

BIOMECHANICAL AND PHYSIOLOGICAL DEMANDS ASSOCIATED WITH LAPTOP AND
SMARTPHONE USE IN BOTH A SUBCLINICAL NECK PAIN AND HEALTHY STUDENT
POPULATION

By

Victoria Anna Breitner, BHSc

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BIOMECHANICAL AND PHYSIOLOGICAL DEMANDS ASSOCIATED WITH LAPTOP AND SMARTPHONE USE IN BOTH A SUBCLINICAL NECK PAIN AND HEALTHY STUDENT POPULATION

Victoria Anna Breitner

Committee Chairperson: Dr. Brenda Gamble

ABSTRACT

BACKGROUND & AIM: The use of technology has become a global phenomenon and has changed how individuals socialize, work, play, and perform leisure activities. However, the use of technology can result in forward slumped head and neck postures and static muscle loading when used for long durations of time. This may cause or contribute to neck pain (NP) in healthy users and increase the severity of NP in subclinical NP users. The purposed of this thesis was to: 1) determine if slumped/flexed head and neck postures during long duration mobile device use will increase discomfort in both groups, or if a subclinical NP group would experience higher discomfort levels, and increased neck muscle activity and 2) examine if the subclinical NP group produces different cervical spine kinematics compared to healthy individuals. **METHODS:** Eighteen UOIT students (10 healthy participants with no NP during the last 6 months [5 females and 5 males] and 8 subclinical NP participants who have had NP within the last 12 months [5 females and 3 males]) participated. Participants completed two mobile device tasks: 1) A laptop task that was one hour in duration and 2) A smartphone task that was 30 minutes in duration. Participants completed three questionnaires (mobile device usage/frequency, the Neck Disability Questionnaire and the Chronic Pain Grade Scale. Head and thorax kinematics were monitored during each condition, surface electromyography (SEMG) was monitored from six upper extremity muscles bilaterally (cervical extensors, upper trapezius and anterior deltoid) and electrocardiogram (EKG) monitored heart rate and breathing. **RESULTS & DISCUSSION:** The laptop and smartphone tasks had similar discomfort scores reported across the same body segments used in the discomfort score questionnaire (posterior head, posterior neck, posterior left shoulder, posterior thoracic, posterior lumbar and posterior right hand and forearm). No significant differences were found for cervical extensor muscle activity. An EMG gaps analysis identified significant differences within the smartphone task for the number of gaps and average gap time for the right cervical extensor (CE), left anterior deltoid (AD) and left upper trapezius (UT). Average head/neck flexion angles were greater for the smartphone tasks than the laptop tasks. There was a difference of 7.7° of head flexion for healthy participants and 12.2° of head flexion for subclinical participant between smartphone and laptop tasks. The smartphone tasks had more gaze angles greater than -45° than the laptop tasks. **CONCLUSION:** This work is important because it evaluated long duration smartphone and laptop computer usage, which has seen limited attention in the academic literature to date. Further investigation should attempt to determine if the differences found between groups can help identify or pre-determine if an individual may be predisposed to NP or injury due to increased device use.

Keywords: Head and neck flexion, Muscle Activation, Laptop, Smartphone.

DECLARATION

I, Victoria Anna Breitner, declare that this thesis represents my own work except as acknowledged in the text, and that none of this material has been previously submitted for a degree at the University of Ontario Institute of Technology, or any other University. The contribution of supervisors and others to this work was consistent with the UOIT regulations and policies. Research for this thesis has been conducted in accordance with UOIT's Research Ethics Committee.

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CHAPTER 1: INTRODUCTION

INTRODUCTION

According to the Canadian Internet Registration Authority (2013), Canadians are the heaviest users of the internet in the world. In addition, various studies illustrate a growing global trend in the amount of smartphone and laptop computer use (Pew Research Center, 2010; Statistics Canada, 2013; Pearce & Rice, 2013; Sackmann & Winkler, 2013; Straker et al., 2008 & Straker et al., 2009). In Canada, the largest age group of smartphone and other mobile devices are individuals under the age of 35 (Statistics Canada, 2012). This age range corresponds with University students who spend a lot of time on mobile devices, whether for social, leisure or school activities. Older generations (individuals aged 55 years and up) are also seeing an increase in the amount of mobile technology used, however, it is at a slower and smaller pace than younger generations (Statistics Canada, 2012).

This thesis evaluates upper body discomfort, heart rate and breathing, gaze angles, neck kinematics, and muscle activity of six upper extremity muscles during long duration smartphone and laptop tasks. Research that has focused on smartphone and laptop use to date have typically observed upper body kinematics and muscle activity for short amounts of time and often with large breaks between tasks (Ning, Huang, Hu, & Nimbarte, 2015). Measurements and observations for short amounts of time may not be adequate to represent long duration use, common to people that use mobile technology on a daily basis for work and/or leisure. This research is unique in that longer data collection trials were completed in an attempt to provide a more in depth look at cervical spine kinematics and muscle activity during long duration tasks. Additionally, a comparison was made between healthy individuals and individuals with NP. To date, this comparison has seen little attention in the literature and these investigations may be used to identify if movements and techniques predispose individuals to increased risk of upper extremity pain due to prolonged use. However, it should be recognized that even

a 30 minute smartphone and one hour laptop task performed in this thesis is still a small window of time, considering how long many users interact with their mobile devices. The aim was to use these data collection times to better extrapolate the cumulative effects associated with mobile technology usage.

RATIONALE

Many ergonomic studies have investigated posture when interacting with mobile devices which can be found within the references of this thesis. However, most of this work has observed posture and/or muscle activity for short durations of time (from minutes to a maximum of 30 minutes with breaks between tasks) (Niekerk et al., 2014 & Young et al., 2012). The extrapolation of these short duration data collections to long duration cumulative effects (8 hour work day, etc.) may not be an entirely accurate representation of long term use. Since most activities that involve interacting with a mobile device are not static, the short measurement durations of most studies do not provide information on the frequency of movements and types of movements adopted by users over long periods of time (Niekerk et al., 2014). In addition, there have been limited investigations of healthy vs. NP individuals and how they interact with their mobile devices. Studying such groups could provide further insight into the development of pain and if some people interact with their devices in such a way that it can lead to pain development (i.e. healthy individuals becoming a subclinical NP individual).

RESEARCH QUESTIONS / OBJECTIVES

1. To determine muscle activity and recruitment patterns (bilaterally) for the upper trapezius, cervical extensors, and anterior deltoid during long duration mobile computing and smartphone use.

2. To determine if individuals with subclinical NP produce different kinematics and muscle activity patterns than healthy individuals when using laptop and smartphone devices for extended periods of time.
3. To determine what impact long term laptop and smartphone use has on resting heart rate and breathing efficiency.
4. To determine user discomfort scores during prolonged laptop and smartphone use.

HYPOTHESES

H1: Slumped/flexed head and neck postures for long durations will increase discomfort in both study groups, with subclinical NP experiencing higher discomfort levels, and increased neck muscle activity.

H2: The subclinical NP group will produce different (either more frequent postural changes or increased flexion) cervical spine kinematics compared to healthy individuals.

CHAPTER 2: LITERATURE REVIEW

INTRODUCTION

A brief literature review of the anatomy and range of motion (ROM) of the cervical spine is first provided to build a foundation for the literature review. The literature review will provide a broad view of how mobile technology and its associated services impacts the world and funnels down to address the main focus of this thesis that addresses long term mobile technology use on the cervical spine.

This work reviews laptop computer and smartphone use and the potential development of pathophysiological injuries. Five themes relevant to laptop and smartphone use, upper body postures and physiological demands were identified. The themes include: 1) technology use on a global scale, 2) smartphone and laptop computer use, 3) mobile technology use and NP, 4) flexed upper body posture with rounded shoulders (slumped sitting) and the potential for musculoskeletal injuries, and 5) flexed posture, slumped sitting, breathing and heart rate changes associated with device use.

SECTION 1: ANATOMY OF THE SPINE

1.1 The Cervical Spine

The adult human spine is composed of 24 vertebral segments which serve to support and allow movements of the head, neck, limbs and torso (Ibrahim, 2015). It also allows the spinal cord and spinal nerves to exit from the foramen of each vertebrae (Ibrahim, 2015). The spinal column is sectioned into four distinct regions based on the physical and functional characteristics (Ibrahim, 2015). These region include: 1) the cervical spine (C1-C7), which will be the focus of this thesis, 2) the thoracic spine (T1-T12), 3) the lumbar spine (L1-L5) and 4) the sacral spine (S1-S5) (Ibrahim, 2015) (Figure 1).

Distinctions between the different regions of the spine are suggested by the “difference in the shape, size, and structure of... [their]...vertebrae and... [their]...intervertebral joints (Grant, 2002).”

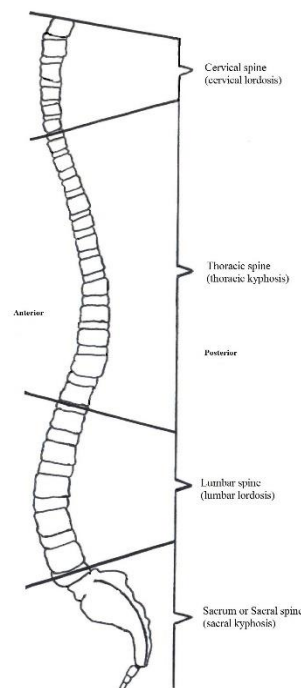


Figure 1: Schematic of the four regions of the human spine (not anatomically correct in the number of vertebrae in total or within each spinal region).

The cervical spine has the smallest vertebral bodies as well as the largest spinal foramina through which the spinal nerve roots travel (Ibrahim, 2015). The head is dependent on the cervical spine for both support and mobility (Ibrahim, 2015). The cervical spine is further broken down into three distinct units based on their characteristics and functions (Ibrahim, 2015):

1.2 The Atlas

The atlas (C1) is the first point of bony contact between the skull and the spine (Ibrahim, 2015). It has the largest vertebral foramen of all the cervical vertebrae (Ibrahim, 2015). Instead of a spinous process the atlas has a posterior tubercle where the nuchal ligament is attached (Ibrahim, 2015). The first cervical nerves exit over the posterior arch of the C1 vertebrae, on both sides of the posterior tubercle, under the posterior atlantooccipital membrane (Ibrahim, 2015). The condyles of the occiput are “cradled” by the superior articular facets of the atlas forming the atlanto-occipital joint (Ibrahim, 2015). The concave atlas and the convex occiput allows for flexion and extension (Ibrahim, 2015) (Table 1).

1.3 The Axis

The axis (C2) resides under the atlas to form the atlantoaxial joint that is secured by the transverse ligament (Ibrahim, 2015). The odontoid process of the axis is the articulation point of the atlas above it (Ibrahim, 2015). In addition to supporting the weight of the head, the atlantoaxial joint allows for a large range of axial rotation (Bogduk and Mercer, 2000). The lateral sections of the atlas and axis, and the anterior arch interact with each other to allow for a large degree of cervical axial rotation (Grant, 2002) (Table 1).

1.4 The Column

The remaining segments of the cervical spine (C3-C7) share the same characteristics of a flat superior surface flanked by processes and a concave inferior surface (Ibrahim, 2015). However, C6 and

C7 differ from the rest of the column in their spinous processes are longer and the C6 spinous process is not divided into two parts (Ibrahim, 2015). All vertebral segments are arranged on top of each other with intervertebral discs separating them (Ibrahim, 2015). Intervertebral discs are cartilaginous pads that are subject to significant compressive loads and serve as shock-absorbers between vertebrae (Ibrahim, 2015). These viscoelastic discs also hold adjacent vertebrae together while allowing slight mobility (Ibrahim, 2015). Each disc is made up of a thick outer layer, called the annulus fibrosis that encloses a gel-like center, called the nucleus pulposus (Ibrahim, 2015). The geometry of the lower cervical column allows for axial rotation and lateral flexion (Ibrahim, 2015).

1.5 Neck Musculature

The muscles used for movement and stability of the head and neck can be divided into the superficial and deep muscles (Ibrahim, 2015). The superficial neck muscles, prime movers of the neck (Jull et al., 2008), can be further divided into the anterior, posterior, and lateral muscles (Table 2). The superficial anterior group is responsible for flexion of the cervical spine, the posterior group for extension, rotation, and lateral flexion, and the lateral group for lateral flexion and extension. The deep cervical muscles contribute to spine stability and slow movements (Bergmark, 1989).

Table 1: Reported maximum ROM values of the neck from Chiu et al. (2002) on 25 healthy participants.

	Mean (°)	S.D.
Flexion	68.0	6.2
Extension	68.3	7.3
Right lateral flexion	49.8	7.5
Left lateral flexion	52.6	7.6
Right rotation	78.0	6.4
Left rotation	77.2	7.6

Table 2: The three groups of superficial cervical extensor muscles and their actions (Ibrahim, 2015).

Group	Muscles	Action
Anterior	1) Longus capitis 2) Rectus capitis anterior 3) Longissimus capitis 4) Oblique capitis superior	1) Flexion 2) Flexion 3) Extension, rotation, lateral flexion 4) Extension, lateral flexion
Posterior	1) Rectus capitis posterior 2) Semispinalis capitis 3) Splenius capitis 4) Trapezius	1) Extension, rotation 2) Extension, rotation 3) Extension, rotation, lateral flexion 4) Extension, lateral flexion
Lateral	1) Rectus capitis lateralis 2) Sternocleidomastoid	1) Lateral flexion 2) Rotation, extension, flexion

1.6 Neck Range of Motion

Chiu et al., (2002) used a Multi Cervical Rehabilitation Unit, designed to measure strength and neck range of motion (ROM), to determine the ROM of 25 healthy participants (10 males and 15 females) in flexion, extension, lateral flexion and axial rotation. Participants sat upright in a chair with restraints over their shoulders to isolate neck motion. Averaged across all participants, extension angle was only slightly greater than flexion angle by $0.3^{\circ} \pm 1.4^{\circ}$. Participants were also able to laterally flex to the left more than they were able to laterally flex to the right by $2.8^{\circ} \pm 0.1^{\circ}$ (Table 1). These results were similar to those reported by Kuhlman, 1993 and Penning and Wilmink, 1987. White and Panjabi, 1990 determined that the middle cervical spine (C4-C5) had the greatest contribution to neck ROM (Figure 2).

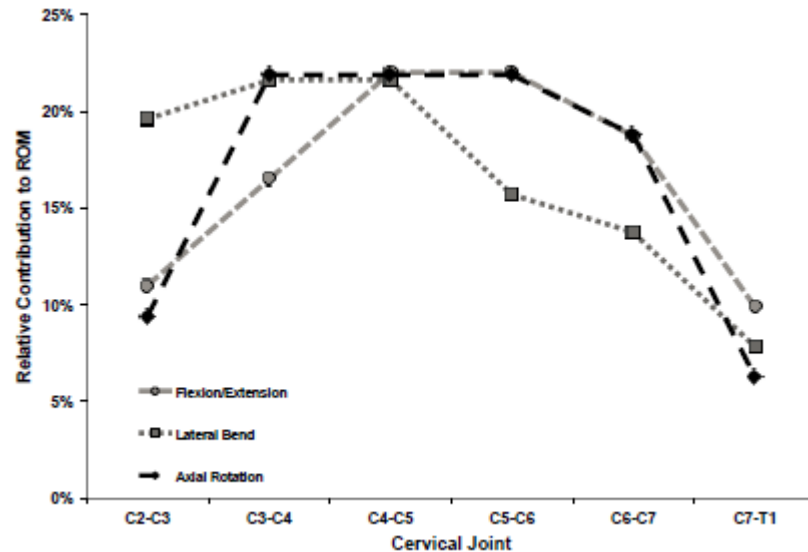


Figure 2: The contribution (in percentage) to neck ROM of each cervical joint for rotations about the flexion/extension, lateral bend, and axial rotation axes. Adapted from White & Punjabi (1990).

1.7 Spinal Nerves

There are 31 bilateral spinal nerves that exit from the spinal column (Ibrahim, 2015). Eight of them originate from the cervical spine (Ibrahim, 2015). The first pair exists between the occipital bone and the atlas, while the rest exit the vertebrae through the intervertebral foramen (Ibrahim, 2015). Two spinal roots, the posterior and anterior roots, branch from the spinal cord and come together at the intervertebral foramen to form the spinal nerve (Ibrahim, 2015). Outside of the vertebral column, the spinal nerve roots branch into the dorsal and ventral rami, or the anterior and posterior branches (Ibrahim, 2015). The posterior branches of the cervical spine innervate the structures of the neck that are found behind the intervertebral foramina (Bogduk, 1982). The anterior branches of the cervical spine make up the cervical plexus and brachial plexus (Ibrahim, 2015). The cervical plexus initiates with the spinal nerves that exit below C1-C4, and can be split into a cutaneous (superficial) and motor (deep) branch (Ibrahim, 2015). The cutaneous branch innervates the skin of the scalp, neck, chest and shoulder while the motor branch innervates certain muscles of the neck, diaphragm and shoulder (Ibrahim, 2015).

The brachial plexus includes spinal nerves C5-T1 (Ibrahim, 2015). The nerves that arise from this plexus include the axillary, musculocutaneous, radial, median and ulnar nerves. These nerves innervate muscles in the shoulders and upper limbs (Ibrahim, 2015). Considering the level at which the brachial plexus nerves exit, these nerves are mechanically affected by neck posture (Ibrahim, 2015). The vertebral joints of the lower cervical spine (C5-C7) contribute between 15 and 25% each to neck flexion, extension, and axial rotation (Figure 2).

SECTION 2: GENERAL TECHNOLOGY USE

2.1 Global Perspective

The use of technology has become a global phenomenon and has changed how individuals socialize, work, play, and perform leisure activities. The Pew Research Center, 2010 surveyed 22 countries (U.S., Poland, Britain, South Korea, France, Spain, Russia, Brazil, Germany, Argentina, Turkey, Japan, Jordan, China, Mexico, Kenya, Lebanon, Egypt, Nigeria, India, Indonesia, and Pakistan) between April 7 and May 8 in 2010 to evaluate this global phenomenon. Some topics of technology use that were surveyed included: Internet usage, devices used to access the Internet, and some of the activities performed when on the Internet. This survey included variables such as computer and smartphone usage, education, age and gender. The majority of people surveyed within the 22 countries have access to the Internet through computers and smartphones, which have increased dramatically since 2002. Sixteen of the 22 countries surveyed illustrated increases in the trends of smartphone ownership. The median percentage of people across the world who own a smartphone has increased 36% since 2002. In 2010, the global median was 81%, compared to 45%, a decade earlier. In 2007, the global median percentage of people owning smartphones (across 16 of the 22 surveyed countries) was 70%.

Computer use has also increased, although at a slower pace than smartphone use. Across 16 of the 22 countries surveyed in 2010, the median percentage of computer users was 50%. As more people use computers and smartphones, the use of the Internet, social media and email have also increased. Internet use had increased from 35% in 2004 to 45% by 2010 for 18 out of the 22 countries. Different countries have varied cultural perspectives which could explain why there were differences in Internet and mobile device use, as found by the Pew Research Center in 2010. Some socio-demographic variables were researched in addition to age and gender to determine if they could impact Internet access and choice of technology device use.

Pearce and Rice, 2013 conducted an interview survey of 1,420 Americans with a 75.4% response rate. They examined if socio-demographic factors or device type were more influential on accessing the Internet and the use of different devices. Demographic differences, access, skills, interests, and infrastructure represented barriers. Therefore, increased technology use, activities, and benefits flow to those with greater resources, abilities, and information needs. Computer and smartphone-based Internet have become more affordable with greater wireless connectivity. The use of a computer by adult Americans has grown slowly from 12.3% in 2005 to 39.5% in 2011. Internet growth mirrors that from 5.4% in 2005 to 34.5% in 2011. Similar to the increase in computer and Internet use, smartphone ownership also grew very quickly in America from 10.5% in 2005 to 91.6% in 2011. Gender typically has direct influence on Internet activities, with women using it more to communicate and for social reasons, and men using it more for information, instrumental, or individual recreational purposes. However the Pew Research Center, 2010 survey found few gender gaps with Internet use. This could be due to changes in time, different variables observed and different cultural perspectives. Another socio-demographic variable examined in America was education. Education has been positively associated with e-mail, information, education, work, business and shopping activities, but negatively with entertainment. This could be due to better-educated individuals being more likely to use the Internet for work, e-mail, search engines, to play games, read blogs, watch videos, and read news, and less likely to use instant messaging (IM) (Pearce, & Rice, 2013). Age was another socio-demographic factor observed within this article. Older users are less likely to use e-mail, search engines, to play games, read blogs, watch videos, and read news, and less likely to use IM. This statement agrees with Sackman and Winkler, 2013 and Statistics Canada, 2013 articles. Economic well-being was another socio-demographic factor observed within this study.

Sackman and Winkler, 2013 examined whether a new Internet generation is emerging. This study used a theoretical and methodological overview of previous research on technology generations and their technology use. Technology generations according to Sackman and Winkler, 2013 are groups of birth cohorts whose conjunctive experience with technology is differentiated by social change. The technology generations examined within this article included: the mechanical generation (born before 1939), the household revolution generation (born 1939-1948), the technology spread generation (born 1949-1963), and the computer generation (1964-1978). These technology generations have difficulty with interface characteristics of computer software introduced after the 1960s. The mechanical and electromechanical generations have greater difficulty coping with computer software. For example, these individuals take more steps and they make more mistakes than individuals born after these generations. Current experimental and survey research on older and younger technology generations indicate that earlier technology generations improve their skills when using new technologies over time. This study concluded that a new Internet generation has emerged which is distinct from the other technology generations. If the elder citizens are persuaded to go online, applications that are similar to older forms like email (letters) and search machines (encyclopaedias) are adopted more quickly (new techno-formats that are more neutral to generation patterns would need to be developed). Despite older generations not using as much technology as younger generations, some Canadian statistics illustrate a slight increase in technology use in older generations. However, this trend is not as dramatic and not for the same activities when compared to younger generations and technology use.

2.2 Canadian Perspective

Statistics Canada, 2013 found that in recent years, older Canadians have increased their Internet usage and are closing the gap with younger Canadians. However, older Canadians do not use the Internet as much for their consumption of some cultural items, namely music listening and video viewing (Statistics Canada, 2013). Older Canadians increased their Internet usage markedly over the

2000s, but remained less likely to use the Internet than younger age groups (Statistics Canada, 2013). In 2010, 29% of people age 75 and over and 60% of those 65 to 74 had used the Internet in the previous month (Statistics Canada, 2013). Internet use among those age 15 to 24 was almost universal (Statistics Canada, 2013). In its early years, the Internet quickly attracted the younger generation (Statistics Canada, 2013). Over the 10-year period from 2000 to 2010, youth became less of a vanguard as older age groups were catching on (Statistics Canada, 2013). Internet use in the previous month by older age groups significantly increased over this period (Statistics Canada, 2013). However, there still was a notable generation gap. The lowest relative rate of activity was among those age 75 and over (Statistics Canada, 2013). This group may be less interested in going online, have difficulty finding what they want, or may face age-related limitations, which would restrict their ability to use computers and the Internet (Statistics Canada, 2013).

These generational trends would apply in any country. However, one would expect these generational and technological trends to be slightly higher within Canada. According to The Canadian Internet Registration Authority (CIRA), 2013, Canadians are the heaviest users of the Internet in the world. The agency's 2013 fact book reports that Canadians have been spending an average of 45.6 hours online per month, compared to 40.3 hours in the U.S. and a world average of 24.4 hours. Canadians watched more online video than people anywhere else, averaging 300 views per month (CIRA, 2013). Another study by *International Telecommunication Union* (n.d.) confirms the results from the CIRA, 2013 study. Furthermore, Canadians are heavy users, with around 90% of users using email at least weekly (*International Telecommunication Union*, n.d.). This 2012 Statistics Canada survey sampled 30,000 households in Canada and showed 83% of Canadian households had access to the Internet at home, compared with 79% in 2010. About 85% of Canadian households located in Census Metropolitan Areas and 80% of households located in Census Agglomerations had home Internet access, compared

with 75% of households outside these areas (Statistics Canada, 2012). The rates of Canadian household Internet access were highest in British Columbia and Alberta at 86%, followed by Ontario at 84% (Statistics Canada, 2012). About 69% of connected Canadian households used more than one type of device to go online in 2012 (Statistics Canada, 2012). Laptop and desktop computers remain the preferred types of hardware for Canadians to access the Internet from home, with 74% and 62% of connected households relying on those devices respectively in 2012 (Statistics Canada, 2012). That said, the proportion of connected Canadian households using wireless handheld devices from home has increased from 35% in 2010 to 59% in 2012 (Statistics Canada, 2012). About 69% of connected Canadian households used more than one type of device to go online in 2012 (Statistics Canada, 2012). In 2013, 21% of Canadian households reported using a smartphone exclusively, up from 13% in 2010 (Statistics Canada, 2014). Exclusive smartphone use is more pronounced in young households when all members are under the age of 35 years (Statistics Canada, 2014). In 2013, 60% of these younger households reported using a smartphone exclusively, up from 26% in 2008 (Statistics Canada, 2014). Exclusive smartphone use is less common in households with individuals aged 55 and older, however, it is slowly rising from 2% in 2008 to 6% in 2013 (Statistics Canada, 2014).

The intensity and scope that Canadians use the Internet was further researched to determine the frequency and duration that technology devices are being used. The findings were also related to some socio-demographic factors. High frequency of technology use, duration and low rest are determinants of injury.

Statistics Canada, 2010 used the data from the 2005 and 2007 Canadian Internet Use Surveys (CIUS) to determine the intensity and scope of Canadian Internet use. The 2005 to 2007 period also saw a slight increase in the proportion of users who were online daily and for at least five hours per week (Statistics Canada, 2010). While this proportion is growing, fewer than 50% of Canadian Internet users

were characterized as high intensity users in 2005 and 2007 (Statistics Canada, 2010). Among individuals with high-speed Internet connections, the low intensity users continued to outnumber the high intensity ones, challenging the notion that access to a high speed connection leads to intensive Internet usage (Statistics Canada, 2010). Among Canadian Internet users, age, income, sex, and years of online experience were all associated with the propensity to engage in online activities and to use the Internet intensively (Statistics Canada, 2010). A starting point for understanding how Canadians incorporate the Internet into their daily lives is frequency of use (Statistics Canada, 2010). In 2007, slightly more than two-thirds of Canadian home Internet users went online at least once a day, representing a small change in frequency of use compared to 2005 (Statistics Canada, 2010). Respondents were also asked how much time they spent online, with less than half of Canadian Internet users reporting that they spent five or more hours on the Internet in a typical week (Statistics Canada, 2010). Measures of frequency of use and time spent online provide some insight into how Canadians use the Internet, but these basic measures do not allow for an examination of different usage patterns (Statistics Canada, 2010). For instance, do daily users stay online for long periods of time? Do some users go online frequently but for short periods of time only? A measure of intensity of use addresses these questions. Fewer than 50% of Canadian Internet users were characterized as high intensity users in 2005 and 2007 (Statistics Canada, 2010). Some would argue that the threshold for categorization as a high intensity user is quite low, but the data shows that the majority of Canadian Internet users did not choose to use the Internet daily and for more than five hours per week from home (Statistics Canada, 2010). Additionally, it is noted that although there is movement away from low intensity usage patterns toward the high intensity patterns, the proportion of high intensity Canadian Internet users increased by just over two percentage points in the two-year period from 2005 to 2007 (Statistics Canada, 2010). Given that approximately 70% of Canadians were Internet users in 2007, this means that fewer than one-

third of all adult Canadians were online daily and spent more than five hours online in a typical week (Statistics Canada, 2010). Based on the classification developed for this study, the majority of Canadians would not be categorized as high intensity Internet users in 2007 (Statistics Canada, 2010). In 2007, about 88% of Canadian home Internet users accessed the Internet with a high speed connection, up from 80% in 2005 (Statistics Canada, 2010). Most Canadian Internet users should now have the technical capacity to take advantage of the benefits that the Internet can offer (Statistics Canada, 2010). But as previous analysis of the Household Internet Use Survey data demonstrated having access to a high speed Internet connection does not mean that a household demonstrates high engagement with the Internet, as measured by intensity or scope of Internet usage (Statistics Canada, 2010). Consistent with this observation, the data above reveals that many Canadians are not high intensity Internet users, regardless of the speed of their Internet connections (Statistics Canada, 2010). While the proportion of high speed high intensity Canadian home Internet users increased from 2005 to 2007, so too did the proportion of high speed low intensity users (Statistics Canada, 2010). However, this Canadian household data continues to challenge the notion that access to a high speed connection leads to intensive Internet usage (Statistics Canada, 2010).

Most Canadian Internet users have been online for five or more years. This is not surprising as high speed Internet connections were available as early as 1996. However, user experience and connection type are also associated with the socio-demographic characteristics of users. For example, the user's age displayed a negative relationship with scope of Internet use, declining as age increases. This support the trends observed in previous articles by Statistics Canada, 2013 and Sackman and Winkler, 2013. The age pattern was particularly strong, with Canadian household Internet users aged 18 to 24 having the highest odds of being high-intensity users. Additionally, the amount of time spent using the Internet increased with users' educational attainment and household income. The model results also

reveal relationships between users' level of Internet experience and speed of connection with intensity of use. The results suggest that experienced users are likely to spend more time online and to use the Internet with regularity. That said, earlier analysis found that patterns of use among the most experienced users changed little over the 2005 to 2007 period, suggesting that experienced users have established usage patterns.

In conclusion, there is an increasing global trend in both computer and smartphone devices used to access the Internet. Some socio-demographic factors have greater impacts than others on the type of devices used to access the Internet. Despite these factors, Canadians are the highest proportionate global consumers of the Internet using smartphones and computers (laptops, desktops, tablet computers) (CIRA, 2013). Canadian household Internet users aged 18 to 24 years old have the highest odds of being high-intensity users, with high intensity household Internet use being defined as being online daily and for five or more hours per week (Statistics Canada, 2008).

SECTION 3: IMPORTANCE OF POSTURE DURING SMARTPHONE AND LAPTOP USE

Increasing device convenience and portability has led to increased frequency and duration of mobile device use. The design characteristics of smartphones and laptop computers are being pushed towards smaller and lighter versions which can negatively impact posture and the musculoskeletal system over time. This second theme identifies the importance of good posture, NP, how musculoskeletal disorders occur, current literature about computer and smartphone use, biomechanics of the upper body, data collection duration, and current ergonomic recommendations when using mobile devices. Previous ergonomic research has acknowledged a relationship between upper body forward flexed postures and musculoskeletal injuries, whether it is injury to the upper body (i.e. shoulders, neck, upper back) or within the arms and hand (i.e. thumbs and wrists) when interacting with external mobile devices. As individuals interact with the screens and keypads of their smartphones and use their laptops for excessive durations, they adopt static flexed head, neck and rounded shoulder posture which results in a slouched position. Current understanding of cervical spine biomechanics during a user's interaction with touch screen mobile devices is limited (Ning et al., 2015). Most ergonomics research into mobile device usage has observed posture when interacting with external devices for short durations of time (Straker et al., 2009; Werth & Reeves, 2014; and Lee et al., 2014). However, measurements and observations for short durations of time may not be adequate to represent long duration usage.

3.1 Why Good Posture is Important

Bernard et al. (1997) identified 27 studies that report a strong association with neck posture and neck MSDs in occupational tasks. Non-neutral neck postures impose significant demands on the muscles and tendons of the neck to ensure stability of the head, which results in an increase in spinal loading (Szeto et al., 2005). Neck flexion is reported to cause neck discomfort and upper limb disorders (Ohlsson et al., 1995; Hünting et al., 1980). Due to the mass of the head, forward flexion of the

head/neck results in a three to six times increase in the load on the C7-T1 joint when compared to a neutral posture (Finsen et al., 1999).

Good or ‘neutral’ spinal postural alignment occurs when the centre of mass of each spinal vertebra is vertically aligned with the spinal vertebrae below. To maintain a neutral spine posture, enough muscular force must be generated in relation to body weight to control the internal relationship of body segments (Brink et al., 2014). Poor head and neck posture is defined as a forward flexed head posture, which is a combination of lower cervical flexion (C7 to C4) and upper cervical extension (C3 to C1). Poor shoulder posture is defined as a combination of scapular abduction and elevation. Coupling of these two postures results in a “hunched” posture, which abnormally loads segments and increases stress on surrounding muscles in the upper body.

When interacting with mobile devices, non-neutral postures can be adopted immediately or developed over time as a result of using built in keyboards and mouse pads. Poor posture in the cervical spine and scapula during prolonged sitting have been linked to discomfort and pain within the muscles, joints and, or, tendons if held for long durations of time or with high frequency of movements (Genaidy & Karwowski, 1993). A study by Hansraj, 2014 determined that the adult head weighs approximately 10 to 12 pounds in a neutral position (head up, eyes looking forward, and back straight) but when an individual flexes their neck, the head mass creates an external moment that places significant internal force on the cervical spine and surrounding structures. Hansraj, 2014 concluded that 15°, 30°, 45° and 60° of head flexion produced 27, 40, 49 and 60 pounds of pressure on the neck, respectively. This is important to note because observational studies by Gold et al., 2012; Sauter et al., 1991 and Werner et al., 2005 utilized checklists to characterize upper body postures during daily smartphone use. These studies could only hypothesize, and not quantify, the magnitude of joint loading as a result of forward flexed head and neck postures. Of the observed individuals during smartphone use, 91% had a flexed

neck, increased shoulder elevation, and non-neutral wrist postures while typing (Gold, et al., 2012). A neutral wrist posture has the hands in line with the forearm, however, when typing on a smartphone, the wrists are flexed compared to being extended when typing on a laptop computer. Both of these typing tasks creates non-neutral wrists. Another study observing smartphone tasks such as text messaging, web browsing and video watching when sitting and standing found that participants produced the greatest head flexion angles when sitting (Lee et al., 2014). Despite the above studies focusing on smartphone use, similar head and neck flexion angles and biomechanical stress could also be applied to individuals who use laptop computers for long durations.

3.2 Neck Pain and Mobile Device Use

Bernard et al., 1997 systematically reviewed over 40 epidemiological studies on the effects of workplace demands on neck musculoskeletal disorders (MSDs). They found evidence that repetitive work and forceful exertions contributed to neck and shoulder MSDs. Furthermore, they found strong evidence that the neck and shoulder are at a significantly increased risk of MSDs when prolonged static loads, contractions, and extreme postures are required of a worker. Tension neck syndrome (TNS), associated with muscle fatigue, stiffness, and pain in the neck and shoulder, is a common MSD found in computer users – a task that typically involves prolonged flexed neck and upper back postures (Mekhora, 2000). These same postures are also observed with prolonged smartphone use when texting, gaming or browsing the internet. Posture, neck loads, receptive work, and fatigue are risk factors for neck musculoskeletal injuries and pain (Finsen, 1999; Knight and Baber, 2004; Bernard et al., 1997; Sommerich et al., 2000; Winkel and Westgaard, 1992).

NP is a major problem in modern society (Bernard et al., 1997; Lee et al., 2001), which frequently becomes chronic and/or recurring (Hoving et al., 2004). Sedentary office workers face a particularly high risk of developing NP, primarily due to low level muscle loading for long periods to

time (Ariëns et al., 2000 & 2001). Individuals experiencing minor symptoms or subclinical NP (NP that does not have to be persistent or chronic but the participant has not received medical treatment) often present with changes in neck range of motion, muscle endurance, and proprioception (Lee et al., 2005). This is most likely due to individuals experiencing subclinical NP may fail to completely turn off and rest muscles which is common with back pain (Callaghan & Dunk, 2002). Neck pain is the most severe MSD problem among mobile handheld device users (Berolo et al., 2011). As a result of NP, individuals will have a reduced cervical ROM (Hagen et al., 1997; Jordan et al., 1997; Lee et al., 2005 & Jull et al., 2007). This may be due to protective mechanism for pain avoidance. It is also speculated that NP individuals will adopt different postures than healthy individuals when interacting with their mobile devices for long durations. A study by Rudolphsson, Björklund, & Djupsjöbacka, 2012 concluded that individuals with chronic NP had reduced extension in the upper cervical region and reduced flexion in the lower cervical region when compared to healthy individuals when seated. Forward head posture has also been found in individuals with NP (Yip et al., 2008). A reduced range of extension for the upper region in individuals with NP may reflect a habituated sitting posture including a more extended upper cervical spine (Rudolphsson et al., 2012). The greater relative reduction in ROM for the lower region could reflect an unwillingness to flex and extend the lower cervical regions, since that would cause a greater center of mass migration of the head, and thus, increase the torque in the cervical spine, increasing muscle and joint loading (Rudolphsson et al., 2012).

3.3 Musculoskeletal Disorders

Upper body musculoskeletal disorders can develop as a result of, but not limited to: repeated loading, awkward postures, mechanical pressures, increased force of exertion, and extended durations of loading (Chany, Marras, & Burr, 2007). Of these risk factors, awkward (or non-neutral) postures and extended durations of loading can be associated with smartphone and laptop computer use. Repeated

sub-maximal exertions, performed over long periods of time can result in cumulative neck loading, which can link laptop computer and smartphone use to increased risk of upper extremity musculoskeletal disorders through a combination of poor head and neck postures and low level static exertions of the neck musculature (Chany et al., 2007). With both laptop computer and smartphone use, neck musculature has to stabilize the head and neck for visual purposes. Low level static exertions can lead to musculoskeletal fatigue if performed for extended durations. The ‘Cinderella hypothesis’ proposed by Hägg, 1991 states that continuous activation of slow twitch motor units (motor neurons that stimulate muscle fibers to contract the muscle) occur during low level muscle contraction, and recent research provides experimental support for this theory (Forsman et al., 2002; Zennaro et al., 2003). The continuous activation of motor units can develop trigger points (areas of high irritability in a muscle, resulting in pain) which has been shown to occur during computer work, suggesting that low level static muscular exertions can lead to muscle injuries (Treaster et al., 2006). The most reported upper extremity musculoskeletal symptom when using smartphones and laptop computers is muscle pain. The Cinderella hypothesis can also be applied to smartphone use since static low level muscle contraction is also produced when interacting with the device. To further research upper extremity muscle activation and the development of pain, a review by Sommerich et al., 2000 examined surface electromyography (SEMG) articles to examine neck muscle activity. One article by Jensen et al. (1998) found that musculoskeletal symptoms in the neck (70%) were higher than other regions of the body, including, low back (54%), shoulders (54%), and hands/wrists (52%). The neck, shoulders, and hands/wrists are needed when interacting with mobile devices while the low back can be affected when sitting for long durations. The anatomy of the neck is complex with many types of tissues in the cervical region that can be sites of pain, including the muscles, intervertebral discs, ligaments, and facet joints. Static work with laptop computers and smartphones can develop tension neck syndrome (myofascial pain) or myalgia (Grieco et

al., 1998; Hagberg et al., 1995 & 1987). Static work concentrates the workload on fewer muscle groups, which may develop musculoskeletal fatigue (Stock, 1991). Even at joint loads as low as 5% of maximum capacity, localized muscle fatigue has been shown to develop during sustained contractions (Sjøgaard et al., 1986).

Many studies have quantified neck strength and have discussed variables that would alter the force generating capacity of the neck such as posture, gender and fatigue. It is important to understand the functional capacity of the neck so ergonomists can accurately determine acceptable loads. If neck strength demands are greater than the neck's moment generating capacity, injuries can arise. Furthermore, sustained submaximal static contraction, coupled with insufficient rest times, lead to muscle fatigue and are a risk factor for injuries and discomfort (Chaffin, Andersson, & Martin, 2006). Westgaard et al., 1986 reported that increased reports of worker neck and shoulder musculoskeletal injuries are correlated with increased static, submaximal activity of the upper trapezius.

Chiu et al., 2002 used a Multi Cervical Rehabilitation Unit (MCRU) to record both the cervical strength and ROM of 91 healthy participants. They tested 45 men aged 20-84 years old, and 46 women aged 20-80 years old, to build a database of cervical strength as well as to determine variables that affect strength such as age, gender, and anthropometrics. Sitting restrained and upright in an adjustable chair, participants wore a head brace fitted with a load cell. They contracted as hard as possible against the brace with 10 seconds of rest between each contraction and two minutes rest between each neck action. Chiu et al., 2002 recorded three measurements each for flexion, extension, left lateral flexion, right lateral flexion, protraction, and retraction. The authors did not record flexion and extension strength in a neutral neck posture. This may be due to the participants being stronger at 20° of flexion and extension for men, and at 40° of flexion and extension for women than in neutral. Lateral flexion strength was recorded at 20° of lateral flexion. These values represent the highest strength compared to any other

position. Chiu et al., 2002 reported that male isometric strength was 1.2-1.7 times greater than that of females. Postures between males and females were not consistent in flexion and extension. The data from the study of Chiu et al., 2002 was presented illustrating why NP may be more prevalent within females. This data could also be used to show that certain neck postures may present a smaller percent maximum of muscle activity than smaller muscles or weaker necks.

In an attempt to reduce the risk of musculoskeletal injury, research has attempted to determine which aspects of mobile device use most likely causes musculoskeletal injury. Through research, preferred grip sizes and muscle force-length relationships that maximize strength and minimize muscle activity has been determined. Muscle moment arms, which are determined by joint posture, can affect the force generating capacity of a muscle. The muscle force-length relationship demonstrates that muscles have the greatest ability to generate active force when close to their resting length which is often in a neutral posture (Chany et al., 2007). The current trend in smartphone and laptop computer design continues to decrease device size, which may force the user into postures that sub-optimize these principles, which could result in injury (Chany et al., 2007).

3.4 Computer Use

Straker et al., 1997 highlighted some of the head and neck concerns associated with laptop use, particularly in terms of postural constraints and discomfort. Discomfort due to non-neutral postures during laptop computer use begins as early as 20 minutes of continuous use and therefore, many ergonomic guidelines recommend that laptop computer use be limited to shorter periods of time (Straker et al., 1997). However, this is not always possible for many occupations, or with students who use laptop computers on a daily basis during classes which last over 20 minutes. Laptop computers are also frequently used in non-traditional settings such as on an individual's lap, while sitting on a couch. Werth & Reeves (2014) observed forearm and neck muscle activity, as well as wrist, forearm and neck posture

when using three portable computing devices (laptop, netbook, and slate computer) in two work settings (adjustable desk with adjustable chair and sofa) during data entry tasks for 30 minutes. This study was based on the hypothesis that smaller portable computers in non-traditional settings (i.e. the lap) could increase the potential of developing musculoskeletal disorders. Previous research has indicated that laptop computers result in greater neck flexion angles (Price & Dowell, 1998; Straker et al., 1997; Sommerich et al., 2002; Seghers et al., 2003) and reduced range of neck motion which could lead to greater discomfort (Straker et al., 1997). A potential reason for these poor working postures and increased discomfort is the connected keyboard and monitor in laptop designs which allows them to be portable. This reduces the ability to adjust the computer monitor separately from the keyboard unlike desktop computers. A few studies have attempted to assess injury risk associated with using laptops in non-traditional work environments (i.e. working with the laptop on the lap) (Asundi et al., 2010; Moffet et al., 2002). When using a laptop positioned on the lap, head-neck and wrist postures were found to be more non-neutral, potentially increasing injury risk to these areas (Asundi et al., 2010; Moffet et al., 2002). However, performance was not affected by computer use location, lap vs. desk (Moffet et al., 2002). The slate computer was found to result in the lowest muscle activation and these levels differed significantly from laptop and netbook activation levels (Werth & Reeves, 2014). The slate, laptop notebook and laptop computers had an average muscle activity of 0.038, 0.0427, and 0.0462 percent of maximum, respectively (Werth & Reeves, 2014). The mean neck posture when using the notebook computer was 6.41°, 8.03° for the slate computer and 4.00° for the laptop computer (Werth & Reeves, 2014). In general, participants assumed a flexed neck posture when typing regardless of the work setting and the slate computer increased wrist, neck and elbow flexion compared to the laptop or netbook (Moffet et al., 2002). Working on the netbook on the sofa resulted in significantly more head flexion than when working on the netbook or laptop at a desk (Moffet et al., 2002). These findings indicate that

using more compact computers may present increased risk for injury to the neck and upper extremity. Other studies to observe desktop computer use have reported 20° or less of head flexion, and between 20° and 25° of head flexion when using laptop computers in non-desk settings such as the lap (Gold, et al., 2012; Moffet et al., 2002 & Turville et al., 1998). The desktop and laptop head flexion angles could contribute to the development of musculoskeletal disorders if these adapted postures are maintained for long durations of time (Ariëns et al., 2001; Sommerich et al., 2001 & Straker et al., 2009).

3.5 Smartphone Use

With technology development striving to make new technological devices smaller, lighter and portable, it could create increased risks of developing upper body musculoskeletal injuries. However, some mobile device companies are trying to incorporate a larger screen while still keeping the device light and portable. A study by Kietrys, Greg, Dropkin, & Gold, 2015 illustrated greater finger flexor, wrist extensor, and trapezius muscle activity as touch screen size increased during a short duration texting task. Cervical flexion and trapezius muscle activity tended to increase as the weight of the mobile device increased with larger touch screen sizes since they are more likely to be placed on the lap compared to smaller devices which would be held with the hands (Kietrys et al., 2015). The increased cervical flexion helps explain the trend for an increase in trapezius muscle activity as screen size becomes larger. As cervical spine flexion increases, the upper trapezius works harder to produce a counterbalancing force to offset the increased flexion moment produced by the mass of the head. This creates stress on neck structures and helps explain why Gustafsson, 2012 found that individuals who interacted with their mobile devices and sat with their head in forward flexed position more commonly experienced musculoskeletal injury symptoms.

Gustafsson, Johnson, Lindegard, & Hagberg, 2011 investigated possible differences in muscle activity and kinematics in texting techniques with a smartphone within young adults with and without

musculoskeletal symptoms. This study concluded that postures adopted when sitting or standing greatly impacted muscle activity of the trapezius muscles with individuals who had musculoskeletal symptoms illustrating fewer pauses compared to those without (Gustafsson et al., 2011). This study also found differences in texting technique between individuals who had musculoskeletal symptoms and those without when texting on a smartphone (Gustafsson et al., 2011). Sitting with the head bent forward was more common in the group with musculoskeletal symptoms compared with the group without symptoms (Gustafsson et al., 2011). The conclusions of this study are similar to other studies that have determined computer users with neck and shoulder discomfort have a tendency for greater head and neck flexion than computer users who do not report neck and shoulder discomfort. Two prospective cohort studies both found an increased risk for neck or neck and shoulder pain or sick leave due to NP during work with neck flexion greater than 20° for more than 40% of the working time and greater than 45° for more than 5% of working time (Ariens et al., 2002, Andersen et al., 2003). Gustafsson et al. (2011) also found that individuals who used a forearm support when sitting, decreased trapezius activity.

Recently, a greater emphasis has been placed on head and neck postures while using smartphones. Lee et al., (2014) assessed the range of head flexion during smartphone use during three common smartphone tasks (text messaging, web browsing, and video watching) while sitting and standing in healthy individuals. Each task was continuous for two minutes while posture was measured using a motion capture system (Lee et al., 2014). This study concluded that participants maintained head flexion of 33° to 45° from vertical when using a smartphone (Lee et al., 2014). Head flexion was significantly larger when sending text messages than the other two tasks, especially when sitting (Lee et al., 2014). Similar to the computer users in the previous studies, Lee et al., (2014) concluded that smartphone users produced greater head flexion angles (33.3° to 44.8° in the 50th percentile). Therefore, the biomechanical loads produced on the neck would be greater for smartphone users than laptop users.

The head flexion angles in the Lee et al., (2014) study is comparable to the head flexion angles produced when using tablet computers on the lap or table in a sitting position, which ranges from 15° to 25° of head flexion (Young et al., 2012). However, it is difficult to conclude that smartphones produce greater head flexion angles than tablet computers due to differences in usage conditions (Young et al., 2012). Among the three tasks that were tested by Young and colleagues, text messaging caused the largest head flexion and it may explain why NP symptoms of heavy smartphone users is often called ‘text neck’. Longer duration of use and higher frequency of use, together with larger head flexion during text messaging, may indicate that text messaging could be a key risk factor for neck problems of smartphone users. This result reinforces the importance of ergonomic interventions to reduce or eliminate either the long duration or large head flexion associated with text messaging. Periodic rest breaks could be an efficient low-cost recommendation to lessen the cumulative loads associated with long duration text messaging. Posture should not static for long durations of time. Therefore exposure to static posture over long durations could result in discomfort and pain within the muscles, joints, tendons and other soft tissues (Genaidy & Karwowski, 1993).

Many studies have measured hand and forearms when participants interact with mobile technology. A study by Berolo et al., (2011) surveyed Canadian university staff and students to determine the distribution of mobile device use, the distribution of upper extremity musculoskeletal symptoms, and the relationship between device use and symptoms. Most participants reported pain in at least one body part with right hand pain being the most common at the base of the thumb, followed by right shoulder pain and NP (Berolo et al., 2011). Case reports suggest a link between high keystroke counts and hand disorders, specifically De Quervain’s tenosynovitis and osteoarthritis of the first carpometacarpal joint in the hand. Laboratory work has shown that, due to small spacing on the mini-keyboard, greater static strain may be placed on the hand and arm muscles during smartphone use as

compared to desktop or laptop use. In addition, laboratory work has demonstrated that as the thumb moves along the interface of the mini-keyboard during a task such as text messaging, it is placed toward the end of its range of motion (Jonsson et al., 2007). Jonsson et al., 2007 described typical thumb postures during text messaging and found that the thumb approaches 79% of its maximum range of motion when abducting in the adduction/abduction plane and 55% of its maximum range of motion when flexing in the flexion/extension plane. Placing the thumb in these static postures likely puts unfavourable static loads on the extrinsic and intrinsic musculature of the thumb. Furthermore, most mobile device tasks require users to look sharply downwards or to hold their arms out in front of them to read the screen; this could lead to fatigue and pain in the neck and shoulders. It is hypothesized that measures of higher daily mobile device use are associated with more musculoskeletal symptoms in the upper extremity, upper back and neck within the Canadian university population. A study by Chany et al., 2007 compared a flip smartphone with a traditional landline phone in the development of upper body discomfort and muscle fatigue over time. Body discomfort information (using subjective discomfort surveys) and muscle activity were monitored on four upper extremity muscles, trapezius, anterior deltoid, flexor digitorum superficialis, and thenar muscles. Participants with short limb lengths developed more severe signs of thenar fatigue. Participants with longer arms developed greater discomfort in the neck, shoulder, and back. The deltoid confirmed this occurrence, showing signs of muscle fatigue. Phone design and anthropometry influenced the development of discomfort and fatigue during phone use. Phone design dictated grip style, resulting in differing discomfort and fatigue levels. Anthropometry influenced the severity of the discomfort and fatigue present in the shoulder and hand.

3.6 Upper Body Biomechanics

Some literature was reviewed to note the current but limited understanding of cervical spine biomechanics during the operation of touch screen mobile devices. Research has been done on arm and hand biomechanics during the use of mobile devices such as Young et al., 2012, who evaluated different tablet computer configurations on wrist, shoulder and neck postures. However there is still a lack of research that has quantitatively investigated neck postures and muscle activities during the use of different mobile devices with various screen sizes. A study by Ning et al., 2015 evaluated neck extensor muscle activity and cervical spine kinematics during the operation of a touch screen tablet and a smartphone. This study demonstrated that users maintained greater neck flexion when using touchscreen mobile devices, especially with smartphone use (Ning et al., 2015). In the first condition, mobile devices were placed on a flat table surface, adjusted to elbow height of participants (referred to as the “table” condition) (Ning et al., 2015). In the second condition, participants were required to hold the device using their left hand during the operation (referred to as the “handheld” condition) (Ning et al., 2015). The tasks involved (reading, typing and gaming) required mostly head and neck flexion without much rotation or lateral bending (Ning et al., 2015). The kinematic analyses revealed that participants maintained significantly greater neck flexion while using a smartphone (44.7°) as compared to a tablet (Ning et al., 2015). The “Typing” task introduced the greatest average neck flexion angle (45.6°); while in “Gaming” and “Reading” tasks, the neck flexion angles were on average 43.6° and 42.4° when using a smartphone. These neck flexion angles were greater than during the tablet condition (Ning et al., 2015). Larger neck flexion angles (5.0°) were also observed when using mobile devices on a table than in handheld conditions (Ning et al., 2015). The different visual and physical interaction requirements could also affect the amount of neck flexion during the use of mobile devices. A previous study concluded that holding a neck flexion angle of more than 20° for a prolonged period of time could

increase the risk of neck injury (Andersen et al., 2003). In Ning et al.'s, 2015 study, the neck flexion angles produced in the conditions exceed the limit proposed by Andersen et al. (2003) and thus, prolonged use of a mobile device could pose significant risks for the development of neck injury. The short duration of the experimental task is the main limitation of this work and future studies should investigate the impact of prolonged mobile device usage on shoulder and cervical tissues.

Trunk posture has been debated throughout the literature with no consensus on the best trunk posture (i.e. upright sitting posture, a backward tilting posture or a forward tilting posture) when using laptop computers (Dainoff & Dainoff, 1987; Grandjean et al, 1987; Mandal, 1985). However, there is consensus among the research on adopting postures with minimal shoulder flexion and neck flexion (Straker et al., 1997). Prior research has suggested that increased neck and shoulder flexion increases the biomechanical load on surrounding structures, leading to discomfort and possibly the development of musculoskeletal disorders (McPhee, 1990). For instance, Columbini, et al., 1986 showed a load of around 280 Newtons (N) on the cervical disc between the sixth and seventh cervical vertebrae with neck flexion of around 11° to 16° (subjects looking straight ahead at an interactive screen) increased by 2.5% to around 350N when neck flexion was increased to around 34° to 41° (subjects looking at interactive screen on a desk surface). Chaffin, 1973 had previously demonstrated that an increase in neck flexion with an increase of muscle load would result in earlier fatigue of the neck muscles which could result in injury.

3.7 Data Collection Durations

Previous ergonomic studies have only observed static posture for short durations of time (Straker et al., 2009; Werth & Reeves, 2014; and Lee et al., 2014). Since most activities that involve interacting with a mobile device are not static, the short measurement durations of most studies do not provide information on the frequency of movements and types of movements adopted by users over long periods

of time (Niekerk, Louw, & Grimmer-Sommers, 2014). Niekerk, Louw, & Grimmer-Sommers, 2014 attempted to address this gap by observing the frequency of postural changes of adolescents when sitting using a desktop computer for a continuous 15 minutes. Each student was given the same typing and mouse activity to complete (Niekerk et al., 2014). Posture variability was focused on the pelvic, thoracic and head angles (Niekerk et al., 2014). The head angle showed the greatest frequency of movements compared to the thorax and pelvic angles (Niekerk et al., 2014). However, the pelvic and thorax angles produced large variations in the number of movements (Niekerk et al., 2014). Niekerk et al., 2014 was the first to apply a method of prolonged data capture to describe sitting posture. Based on the results of this study, sitting posture over a long duration of time is dynamic and cannot be predicted from short periods of time. This is evident from work which has focussed on the lumbar spine when sitting for long durations of time (Callaghan & Dunk, 2002 & De Carvalho, 2008). This work found gender differences in lumbar spine shape when sitting which is due to differences in the skeletal anatomy of the male and female pelvis (Van der Graaff, 2002) which leads to biomechanical differences in the way men and woman sit (De Carvalho, 2008). For instance, when sitting in office chairs females produce more lumbar lordosis with a vertical trunk and tend to sit more upright and perched at the front edge of the seat. Males tend to slouch with a more posteriorly rotated pelvis and sit further back in the seat (Dunk and Callaghan, 2005). However, similar research for gender differences in cervical spine posture during long durations of sitting has not been clearly supported in the literature (Dvorak et al., 1992; Trott et al., 1996; McClure et al., 1998; Mannion et al., 2000). It is well documented that age does effect the cervical spine (Yoganandan, et al., 2001), since aging decreases cervical ROM. Variances in cervical ROM due to gender are less consistent in the literature. In a study comparing 150 healthy subjects of mixed gender, Dvorak and associates in 1992 found that the ROM of the cervical spine decreased in all planes with increased age, except axial rotation following maximal flexion of the cervical spine (Dvorak et al.,

1992). The authors attributed this to a compensatory mechanism for the reduced motion in other regions of the cervical spine. They also found significant differences between gender groups within the same age range. Women tended to show greater ROM in all planes in the 30-39 age group and a greater ROM in the 40-49 age group in axial rotation in the neutral position and axial rotation. When the cervical spine was fully flexed. Men showed significantly higher differences in lateral bending and axial rotation following maximal extension of the cervical spine in the 50-59 age group. No significant differences between genders were found in the 20-29 group and over 60 age groups.

3.8 Current Ergonomic Smartphone and Laptop Recommendations

Gustafsson, 2012 provided some ergonomic recommendations for smartphone text messaging to reduce the risk of musculoskeletal disorders among young intensive smartphone users. The majority of reported musculoskeletal injuries from young people who use their smartphone for intensive texting report injuries in the hand and forearm (Gustafsson, 2012). This study compared texting on a smartphone in healthy controls to individuals with musculoskeletal disorders in the neck and or upper extremities (Gustafsson, 2012). Differences were noted in physical load, muscle activity, and kinematics between the groups (Gustafsson, 2012). The musculoskeletal group sat with their head flexed, no forearm support and send text messages with one thumb (Gustafsson, 2012). When using a forearm support, trapezius muscle activity decreased (Gustafsson, 2012). The high velocity in thumb movements when sending texting messages was associated with increased muscle activity in the forearm extensor muscles (Gustafsson, 2012). Based on these findings Gustafsson, 2012 made some ergonomic recommendations when texting which included: supporting the forearms (e.g. table, thighs or arm rests of a chair), using both thumbs when sending text messages, not sitting with the head bent forward, and not sending text messages with high velocity hand/finger motion (Gustafsson, 2012).

Genaidy & Karwowski, 1993 measured discomfort ratings when deviating from neutral posture while sitting and standing. The regions of the body that were observed included: the wrist, elbow, shoulder, neck, low back, hip, knee, and ankle. Genaidy & Karwowski, 1993 concluded that lateral flexion of the neck produced the highest discomfort ratings in both the standing and sitting positions. For the forearm, supination resulted in the highest discomfort ratings in both sitting and standing positions (Genaidy & Karwowski, 1993). The discomfort ratings for both elbow flexion and extension were almost identical (Genaidy & Karwowski, 1993). Pronation of the forearm led to slightly higher discomfort values than both flexion and extension, but lower than supination (Genaidy & Karwowski, 1993). The perceived joint discomfort values were almost the same for hand movements around the wrist in both the sitting and standing positions (Genaidy & Karwowski, 1993). Many of the observed postures can be found when people are interacting with their smartphone and laptop computers. Most individuals that use these technological devices maintain static upper body postures for long durations of time. Over time, it is expected that users will start to slouch forward due to the biomechanical consequences of creep and a need to alter discomfort (Beach, Parkinson, Stothart, & Callaghan, 2005). Based on the results of this study, it is important to incorporate postural changes during any static activity to prevent the development of musculoskeletal disorders. Movement while sitting is advocated as a way of reducing the occurrence of musculoskeletal symptoms when using mobile devices (McGill and Fenwick, 2009; O'Sullivan et al., 2012; Robertson et al., 2009; van Dieen, De Looze, and Hermans, 2001). It therefore seems important to not only analyze the sum of the total time spent in one posture, but also the number of times a person moves in and out of a specific posture over time (Niekerk et al., 2014). Previous ergonomic studies have shown that by incorporating changes in posture when performing a static task (i.e. sitting and using a desktop, laptop or interacting with a smartphone) could reduce the risk of developing musculoskeletal disorders (Niekerk et al., 2014).

SECTION 4: POSTURAL CHANGES AND BREATHING MECHANICS

Postural demands can also influence breathing mechanics. Interestingly, changes in posture can occur due to habitual lifestyle factors (Kendall et al., 1952; Koskelo et al., 2007; Straker et al., 2008), age (Milne & Lauder, 1974), in association with pathology, pain, or injury (Kendall et al., 1952; White et al., 1977; Findlay & Eisenstein, 2000; Dankaerts et al., 2006).

A study by Segizbaeva et al., (2011) examined the effects of 30° of head flexion on respiration and the muscles associated with breathing in healthy subjects for 30 minutes. The 30 minute duration used in this work is a good start for evaluating long duration changes in breathing mechanics. This study found that the flexed head posture increased inspiratory time, decreased breathing frequency, inspiratory and expiratory flow rate, and increased the airway resistance in comparison to values in vertical posture (Segizbaeva et al., 2011). No significant changes were found in tidal volume and minute ventilation (Segizbaeva et al., 2011). The chest wall inspiratory muscles increased in activity while the diaphragm's contribution decreased during head-down breathing (Segizbaeva et al., 2011). However, maximal inspiration during head-down tilt produced the opposite muscle activity pattern: the inspiratory muscles decreased in activity while the diaphragm's activity increased (Segizbaeva et al., 2011). These results suggest that coordinate modulations in inspiratory muscle activity preserves the function of the inspiratory muscles during short-time head-down tilt (Segizbaeva et al., 2011).

Lin and Peper, 2009 investigated the psychophysiological patterns associated with smartphone text messaging (texting) in college students. Texting was monitored with SEMG on the upper trapezius, abductor pollicis brevis and opponens pollicis, blood volume pulse (BVP) from the middle finger, temperature from the index finger, and skin conductance (SC) from the palm of the non-texting hand; and respiration from the thorax and abdomen (Lin & Peper, 2009). The results indicated that all subjects showed significant increases in respiration rate, heart rate, SC, and shoulder and thumb SEMG as

compared to baseline measures (Lin & Peper, 2009). Eighty-three percent of participants reported hand and NP during texting, and held their breath and experienced arousal when receiving text messages (Lin & Peper, 2009). Most subjects were unaware of their physiological changes (Lin & Peper, 2009). The study suggests that frequent triggering of these physiological patterns (freezing for stability and shallow breathing) may increase muscle discomfort symptoms (Lin & Peper, 2009). Thus, participants should be trained to inhibit these responses to prevent illness and discomfort.

When observing individuals who use their smartphones, individuals will often adopt a variety of sitting postures, which vary by individual and this could be due to changes in discomfort over time. A study by Lee et al., 2010 observed how different sitting postures can affect the chest wall shape and chest wall motion in three dimensions and how this impacts tidal volume when breathing in healthy subjects. It was found that single plane changes in sitting posture (i.e. trunk flexion) alter three-dimensional ribcage configuration and chest wall kinematics during breathing, while maintaining constant respiratory function (Lee et al., 2010). It is well documented that changes in body position (supine vs. standing vs. prone) alter pulmonary function (Crosbie and Myles, 1985; Dean, 1985; Chang et al., 2005). Respiratory muscles also have postural functions (De Troyer, 1983; Rimmer et al., 1995; Hodges et al., 1997a, b; Hodges and Gandevia, 2000; Gandevia et al., 2002). Changes in posture may alter the ability of these muscles to contribute to respiration due to competition between postural demands and breathing or via changes in mechanical efficiency due to length-tension changes (Lee et al., 2010). Some data produced by other studies support the hypothesis that subtle changes in posture may affect breathing. Slump sitting was found to reduce tidal volume, decrease forced vital capacity, and forced expiratory volume in one second and peak expiratory flow when compared to upright postures (Landers et al., 2003; Lin et al., 2006). Other studies that have examined spinal curvature and muscle activity when sitting have found variations in spinal curvature within the sitting posture (Claus et

al., 2009). Variations in spinal curvature is associated with differences in muscle activity (Floyd & Silver, 1955; Donisch & Basmajian, 1972; Andersson et al., 1974; Dolan et al., 1988; Andersson et al., 1996; Callaghan & Dunk, 2002; O’Sullivan et al., 2002, 2006; Claus et al., 2009) and joint orientation (Adams & Hutton, 1980, 1985; Lin et al., 2006), which can influence the rib cage and abdomen and change breathing movements. The study by Lee et al., 2010 predicted that sitting in a slumped posture would reduce the ability of the abdomen to help breath and increase the dependence on thoracic expansion. The reference posture, which was used in this study for comparison to all other postures, is considered by other articles as ideal and referred to as a “neutral” or “ideal” posture by various authors (Kendall et al., 1952; Adams & Hutton, 1985). The absolute difference between tidal volume measures was greater for the slump posture than for the self-selected posture (Lee et al., 2010). This data indicates that if posture is not controlled, differences in posture between subjects may contribute to individual variation in the chest wall shape and kinematics (Lee et al., 2010). Furthermore, changes in postural alignment in people with musculoskeletal impairments, neuromuscular disorders, and/or respiratory disease may have reduced adaptability in the respiratory systems and may have more profound impact on breathing (Lee et al., 2010).

A study by Ono, Otsuka, Kuroda, Honda, & Sasaki, 2000 tested the hypothesis that changes in head and upper body position produce changes in upper-airway dimensions. Magnetic resonance imaging (MRI) was used with healthy nasal breathing patients (Ono et al., 2000). The subjects underwent MRI in three head/body positions: supine, supine with the head rotated, and lateral recumbent (Ono et al., 2000). Ono et al., 2000 concluded there was a significant decrease in the lateral dimension in the lateral recumbent position compared with that in the supine position (Ono et al., 2000). Liistro et al., 1988 reported the upper airway resistance increased during head flexion and was accompanied by a decrease in the surface area of the hypopharyngeal airways. The genioglossus muscle is considered to be

a key muscle in maintaining an open upper airway, since the position of the tongue is largely determined by the activity of this muscle (Ono et al., 2000).

The next study does not follow the same trend as the previous articles indicating that a neutral posture will promote good breathing. A study by Berems, Doro, Heiman, Bredle, & Ishikawa, 2014 investigated whether a hunched sitting posture in middle age and older adults would have an effect on breathing. Two-thirds of elderly women and men already have thoracic kyphosis, or severe curvature of the upper back (Bartynski et al., 2005). This disease reduces thoracic cage size which in turn can reduce lung capacity (Bartynski et al., 2005 & Bellemare et al., 2001). Elderly populations have compromised posture and as a result, reduced lung capacity. However, to Berems et al.'s, 2014 knowledge, no research has been completed to see if improving posture could lead to improvement in breathing. Slow vital capacity (SVC, maximum volume of air that can be exhaled slowly) would be a better representation of every day breathing habits than forced vital capacity (FVC, volume of air that can be forcibly exhaled after full inspiration) (Berems et al., 2014). Recent research has shown that ethnicity does not impact pulmonary function in White, African-American, and Mexican American individuals as traditionally assumed (Kiefer et al., 2011). Normal posture for this study was the posture each participant adopted naturally without instruction (Berems et al., 2014). Ideal posture (IP) was instructed as sitting as straight as possible with shoulder blades pulled back, and chest out (Berems et al., 2014). Poor posture (PP) was instructed as resting elbows on knees in a hunched over position (Berems et al., 2014). Participants rested for 15 minutes prior to testing to ensure that their breathing was normal (Berems et al., 2014). It was hypothesized that poorer posture would result in a decline in SVC but the analysis showed no significant difference in SVC with a change in posture (Berems et al., 2014).

Changes in body posture can greatly impact ventilation, perfusion and arterial oxygen levels in healthy individuals and within individuals with pulmonary disorders by changing the upper airway

structure and surface area (Dean, 1985; Glaister, 1967 & Ono, et al., 2000). Individuals with chronic obstructive airway disease (COAD) and bronchial asthma have decreased minute ventilation and reduced pulmonary venation by 22% when the individuals leaned forward 30 to 40 degrees and flexing the neck 16 degrees (Dean, 1985). Minute ventilation is important to maintain because it controls carbon dioxide concentrations within the blood while pulmonary ventilation is the amount of gas exchange between the lungs and the external environment (Plowman & Smith, 2010). Therefore, a decrease in minute ventilation and pulmonary ventilation will accumulate more carbon dioxide within the blood and could create muscle fatigue due to a lack of oxygen if the forward flexed upper body postures were maintained for long durations. Slumped sitting postures have been shown to decrease forced vital capacity, forced expiratory volume in one second, and peak expiratory flow when compared to upright postures (Ono et al., 2000). Slumped sitting postures can also decrease forced vital capacity (the amount someone can expire after maximum inhalation), forced expiratory volume (how much air someone can exhale in a forced breath in one second) and peak expiratory flow (the speed of expiration) when compared to upright postures (Ono et al., 2000). These are also important pulmonary functions since they help to maintain the amount and speed of gas exchange (Plowman & Smith, 2010). Slumped sitting postures also produce changes in the normal curvature of the spine which is associated with changes in muscle activity and joint orientation which also likely influences the rib cage and abdomen which change breathing kinematics (Ono et al., 2000). This association between chest wall shape and breathing motion also changes during different postures since the external and internal respiratory muscles also have postural functions (Lee et al., 2010). If posture is compromised the muscles may not be able to participate in respiration due to competing demands of posture and breathing (Lee et al., 2010).

Body position directly affects ventilation and perfusion matching and arterial oxygen levels (Dean, 1985). The effect of body position on arterial oxygen levels and lung function is discussed for the

following positions: erect, lean forward, supine, lateral, prone, head-down tilt, hands and knees, and upside down (Dean, 1985). Alveolar ventilation to capillary blood flow (V/Q) matching is the essential mechanism for gas exchange and oxygenation of arterial blood (Dean, 1985). The mismatching of ventilation and blood flow in diseased lungs is a common cause of hypoxemia and hypercapnea, which may precede respiratory failure and death (Dean, 1985). Body position, however, has a direct effect on arterial oxygen tension (PaO_2) (Dean, 1985). The purpose of this article was to provide a greater understanding of the effect of body position on pulmonary function (Dean, 1985). Gravity is the single most important factor responsible for uneven distributions of ventilation and blood flow in the healthy lung (Dean, 1985). Glaister, 1967 examined changes in ventilation and perfusion in subjects in different positions. Age-related reductions in functional residual capacity (FRC) result in airway closure and reduced PaO_2 levels (Dean, 1985). Two "critical ages" at which age and body position can interact to produce closure have been identified as 65 years and 44 years (Dean, 1985). Shifting from the erect position of 30 to 40 degrees to the lean-forward position resulted in a significant decrease in minute ventilation from 6.28 to 5.99 l/min in 22 patients with COAD and bronchial asthma (Dean, 1985). Barach and Beck, 1974 have examined the use of the 16-degree head-down position as a means of producing viscerodiaphragmatic breathing in patients with pulmonary disease. This caused the viscera to displace the diaphragm upward. Pulmonary ventilation was reduced by an average of 22 percent (Dean, 1985).

In conclusion, many ergonomic studies do not observe how an individual's physiology (i.e. breathing) may or may not be effected by posture. Physiology should also be assessed when developing new ergonomic solutions. An ergonomic solution may provide improve posture for example but what is it doing to the individual's physiology? This section illustrates how different head tilt and flexion angles, that are similar to those observed when during mobile device use, affects breathing. There has been little

research done to assess breathing when an individual is interacting with their mobile devices and long term affects are unknown.

SECTION 5: POSTURAL CHANGES CAN INFLUENCE THE CARDIOVASCULAR SYSTEM

Heart rate varies across individuals due to intrinsic and extrinsic factors such as: the time of the day, different postures, fitness level, changes of temperature, and mental activity (MacWilliam, 1933). This could help explain the wide ranges in heart rate recorded in studies that have observed large study populations having the same postures. For example, in a study conducted by Shortt & Ray, 1997 the authors recorded heart rates in males aged 18 to 36 years and they ranged from (64 to 105 beats/minute) in standing, sitting (54 to 89 beats/minute) and lying down (48 to 98 beats/minute). Despite the population size, previous studies have generally found that heart rate changes occur within the first few minutes of a postural adoption and is maintained until a neutral posture is regained (Shortt & Ray, 1997).

Various studies have observed how heart rate is affected in lying, sitting, and standing positions. The carotid sinus reflex is thought to create a lowered heart rate more so in the lying and squatting positions (MacWilliam, 1933). When lying down, heart rate will be slower due to the increase of pressure in the carotid sinus due to the hydrostatic factor in this posture, therefore, there is an association between changes in heart rate with variations in the elevation of the head (MacWilliam, 1933). When subjects are lying down and altering the position of their lower limbs it will influence the cardiovascular system by having negative effects on heart rate and blood pressure (MacWilliam, 1933). This may have affected the heart rate results of Shortt & Ray (1997) when subjects lay prone and performed 10 minutes of head-down neck flexion so the chin touched their chest, heart rate increased during the first minute and remained elevated (71 ± 2 to 76 ± 3 beats/minute), calf blood flow decreased on average 14% (4.6 ± 0.8 to 3.9 ± 0.6 ml·min⁻¹·100 ml), and calf vascular resistance increased 12% (24.0 ± 4.3 to 27.4 ± 4.7 units) within the first two minutes. However, when during head flexion, Essandoh, Durprez,

& Shepherd, 1988 found increased calf and forearm vascular resistance. A study by Lee et al., 2001 concluded the same results but while the subjects were lying prone during a passive head down neck flexion posture. Kneeling and standing postures are similar in the effects on heart rate but the effect on parts of the limbs below the knees is of little significance (MacWilliam, 1933). When bending forward while standing, MacWilliam, 1933 found a decrease in heart rate and concluded that it was not due to changes in blood pressure. However, the authors did not address the possible influence of head flexion and the hydrostatic factors. When standing motionless, heart rate is increased five to ten beats than when standing with slight, continued movements of the lower limbs (MacWilliam, 1933).

The most commonly observed postures when using smartphones and laptops are standing and sitting. Shoulder flexion and a flexed upper body have also been observed when using technological devices. Such as in the study by Lim, Jung, & Kong, 2011 the authors observed the effects of four shoulder flexion angles, two back flexion angles, and combinations thereof on heart rate. As shoulder flexion angles increased it created more of an impact on heart rate than did increases in back flexion (highest under 135°), however, heart rate increased by 21.8% when the back was flexed to 45° and the shoulders were in a neutral posture (Lim et al., 2011). Lin and Peper, 2009 investigated the psychophysiological patterns associated with smartphone text messaging in college students. The authors found an increase in heart rate which they concluded was due to psychological factors of excitement and anticipation when texting and not associating with head or upper body posture. Observing posture with heart rate associated with mobile technology would difficult to decipher if the posture is affecting the heart rate or if it was from excitement when interacting with their devices.

Other studies have observed varying degrees of head flexion on heart rate. When performing a head-down tilt to 20° for five minutes in a supine position with the shoulder supported, Van Lieshout et

al., 2005 concluded stroke volume of the heart was decreased while there was an increase in heart rate associated with 70° of head-up tilt with supported feet.

Other potential areas of the cardiovascular system that could be compromised by altered posture due to an interaction with technological devices have also been investigated. For instance, cerebral blood flow in head down tilt postures was observed by Gelinas et al., 2012 but it was concluded that cerebral blood flow is maintained and not affected during acute severe changes in posture. Subjects rested in a supine position (0°) on a tilt table and exposed to -90° head down tilt and +90° head up tilt in randomized order (10 minutes each level) (Gelinas et al., 2012). Electromagnetic fields are produced by electronic devices, such as smartphones and laptops. Parazzini et al., 2013 observed the effect of electromagnetic fields produced by smartphones on heart rate and concluded there was no significant effects on heart rate.

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CHAPTER 3: MANUSCRIPT

**BIOMECHANICAL AND PHYSIOLOGICAL DEMANDS ASSOCIATED WITH
LAPTOP AND SMARTPHONE USE IN BOTH A SUBCLINICAL NECK PAIN
AND HEALTHY STUDENT POPULATION**

AUTHOR: VICTORIA ANNA BREITNER

AFFILIATION: UNIVERSITY OF ONTARIO INSTITUTE OF TECHNOLOGY

FACULTY OF HEALTH SCIENCES

OSHAWA, ON CANADA

L1H 7K4

1.0 ABSTRACT

BACKGROUND & AIM: The use of technology has become a global phenomenon and has changed how individuals socialize, work, play, and perform leisure activities. However, the use of technology can result in forward slumped head and neck postures and static muscle loading when used for long durations of time. This may cause or contribute to neck pain (NP) in healthy users and increase the severity of NP in subclinical NP users. The purposed of this thesis was to: 1) determine if slumped/flexed head and neck postures during long duration mobile device use will increase discomfort in both groups, or if a subclinical NP group would experience higher discomfort levels, and increased neck muscle activity and 2) examine if the subclinical NP group produces different cervical spine kinematics compared to healthy individuals. **METHODS:** Eighteen UOIT students (10 healthy participants with no NP during the last 6 months [5 females and 5 males] and 8 subclinical NP participants who have had NP within the last 12 months [5 females and 3 males]) participated. Participants completed two mobile device tasks: 1) A laptop task that was one hour in duration and 2) A smartphone task that was 30 minutes in duration. Participants completed three questionnaires (mobile device usage/frequency, the Neck Disability Questionnaire and Chronic Pain Grade Scale). Head and thorax kinematics were monitored during each condition, surface electromyography (SEMG) was monitored from six upper extremity muscles bilaterally (cervical extensors, upper trapezius and anterior deltoid) and electrocardiogram (EKG) monitored heart rate and breathing. **RESULTS & DISCUSSION:** The laptop and smartphone tasks had similar discomfort scores reported across the same body segments used in the discomfort score questionnaire (posterior head, posterior neck, posterior left shoulder, posterior thoracic, posterior lumbar and posterior right hand and forearm). No significant differences were found for cervical extensor muscle activity. An EMG gaps analysis identified significant differences within the smartphone task for the number of gaps and average gap time for the right

cervical extensor (CE), left anterior deltoid (AD) and left upper trapezius (UT). Average head/neck flexion angles were greater for the smartphone tasks than the laptop tasks. There was a difference of 7.7° of head flexion for healthy participants and 12.2° of head flexion for subclinical participant between smartphone and laptop tasks. The smartphone tasks had more gaze angles greater than -45° than the laptop tasks. **CONCLUSION:** This work is important because it evaluated long duration smartphone and laptop computer usage, which has seen limited attention in the academic literature to date. Further investigation should attempt to determine if the differences found between groups can help identify or pre-determine if an individual may be predisposed to NP or injury due to increased device use.

Keywords: Head and neck flexion, Muscle Activation, Laptop, Smartphone.

2.0 INTRODUCTION

Sustained upper extremity (i.e. neck, upper spinal regions, humerus, forearms, wrists, hands and fingers) postures have become part of a global modern lifestyle with the use of different technological devices for work and play. A forward head posture (the anterior positioning of the cervical spine), with an extended neck is commonly adopted when sitting and working at a computer (Fredriksson et al., 2002; Yoo, Yi, & Kim, 2006) and has been associated with NP (Ankrum & Nemeth, 1995; Chiu et al., 2002; McAviney, Schulz, Bock, Harrison, & Holland, 2005; Yip et al., 2008). It has been suggested that maintaining a flexed neck posture for as little as 15 minutes can provoke NP (Harms-Ringdahl & Ekholm, 1986). Sustained postures are associated with a slow deformation tissue creep and may change the physiochemical properties of spinal ligaments (Jirout, 1996; Panjabi, 2006), the disc annulus and the facet capsules (Panjabi 2006). In addition, increased muscle activity in the cervical spine occurs with both flexed and extended head postures for sustained periods of time (Schüldt, 1988). All of which can lead to cumulative tissue and joint loading and increased risk for musculoskeletal injury. To date, there has been little investigation of the effects of long duration mobile device use on cervical spine kinematics, discomfort and cervical muscle activity. Additional insight into long duration usage could aid in the understanding of injury mechanisms and risk associated with mobile device use.

Neutral spine postures occur when the centre of mass of each vertebral body is vertically aligned with the distal vertebrae. However, interacting with mobile devices for long durations of time can result in poor head, neck and shoulder postures, which can create a hunched posture. Bernard et al., (1997) identified a strong association with neck posture and neck MSDs in occupational tasks involving non-neutral postures. Additionally, neck flexion is reported to cause neck discomfort and can lead to upper limb disorders (Ohlsson et al., 1995; Hünting et al., 1980). Forward flexion of the neck results in three to

six times the load on the C7-T1 joint when compared to a neutral posture (Finsen et al., 1999). Forward flexed head postures that can excessively load the cervical spine are most commonly seen during laptop and smartphone use.

Previous studies have reported a forward head posture in people with NP (Yip et al., 2008). The reduced range of extension for the upper region in the NP group may reflect a habituated sitting posture including a more extended upper cervical spine (Rudolfsson et al., 2012). The greater relative reduction in ROM for the lower region could reflect an unwillingness to flex and extend the lower cervical regions, since that would cause a greater center of mass migration of the head and thus increase the torque in the cervical spine (Rudolfsson et al., 2012).

Upper body musculoskeletal disorders can develop as a result of: repeated loading, awkward postures, mechanical pressures, increased force of exertion, and extended durations of loading (Chany et al., 2007). Of these risk factors, awkward (or non-neutral) postures and extended durations of loading can be associated with smartphone and laptop computer use. Repeated sub-maximal exertions, performed over long periods of time can result in cumulative neck loading, which can link laptop computer and smartphone use to increased risk of upper extremity musculoskeletal disorders through a combination of poor head and neck postures and low level static exertions of the neck musculature (Chany et al., 2007). With both laptop computer and smartphone use, the neck musculature has to stabilize the head and neck for visual purposes. Low level static exertions can develop musculoskeletal fatigue if performed for extended durations.

Upper extremity kinematics and muscle activity have been investigated previously during smartphone and portable computer use (i.e. laptops and different kinds of tablet computers) through various studies (Straker et al., 1997, Szeto et al., 2009, Gustafsson et al., 2011, Werth & Reeves, 2014, Ning et al., 2015). Straker et al., (1997) measured discomfort and upper extremity joint angles when

using a laptop computer compared to a desktop computer. The authors found significant postural differences in neck angle and head tilt between laptop computer and desktop computer use (i.e. laptop neck angle of 57.4° compared to desktop neck angle of 50.8° , laptop head tilt angle was -9.8° compared to 1.7° head tilt angle with the desktop computer). There was also a greater trend for neck protection and discomfort scores (27.5 mm for laptop; 22.0 mm for desktop use) when using a laptop. Although Straker et al., 1997 did not measure muscle activity, a study by Szeto et al., 2009 measured muscle activity of the upper trapezius and cervical extensors in female office workers with chronic NP and healthy participants when they adopted two resting postures: 1) with hands on laps, 2) hands on a keyboard and during typing tasks. Szeto et al., 2009 concluded that resting hands on the keyboard significantly increased muscle activity in the right upper trapezius of participants with high discomfort scores, similar to that observed during actual typing. The authors concluded that healthy participants showed no difference in muscle activity between the resting postures which suggests that some muscle activation patterns were triggered by anticipatory task demands in some individuals. Gustafsson et al., 2011 found differences in muscle activity and kinematics in young adults (aged 19 to 25 years) with and without musculoskeletal symptoms when using smartphones for texting. During texting, it was more common (in the group with musculoskeletal symptoms), to sit with the head flexed forward (neck flexion $\geq 40^{\circ}$) and to sit without forearm and back support compared to the group without symptoms (Gustafsson et al., 2011). Lower muscle activity in the left and right trapezius muscles was observed in the group who used forearm support during the given text task compared to those who did not use forearm support (Gustafsson et al., 2011). Ning et al., 2015 observed participants' muscle and cervical spine kinematics when using smart phones and tablet computers during three different tasks (typing, gaming and reading). It was found that participants maintained significantly greater neck flexion when operating a smart phone (44.7°), with the mobile devices set on a table (46.4°), and while performing a typing task (45.6°)

(Ning et al., 2015). Lower levels of neck muscle activity were observed while performing a reading task and holding mobile devices with their hand (Ning et al., 2015). This study demonstrated that prolonged use of mobile devices exposes significant musculoskeletal risk to the cervical spine (Ning et al., 2015). Specifically, using a smart phone on a table and performing a typing task, since this was the highest level of risk among all conditions tested in this study (Ning et al., 2015).

Most investigations of mobile device use have only been for short duration data collections and have had no focus on both healthy and subclinical NP populations. Niekerk et al., 2014 highlighted the importance of long duration data collections by emphasizing that sitting posture will vary over time since sitting is not a static activity and that no one ‘snapshot’ of sitting posture will clearly represent ‘true posture’. Gold et al. (2012) quantified and compared sitting postures while working on a laptop computer. Typing was performed in three positions for seven minutes per task while data capture took place for three minutes. Stakers and Mathiassen, 2009 compared sitting posture while interacting with mobile devices and participants completed three different tasks for 10 minutes each. Data was captured at three different intervals, starting on the second, fifth and ninth minute. Xie et al., 2015 completed different forms of texting on a smartphone (texting with both thumbs, texting with right thumb only and typing on the desktop computer keyboard with both hands) and desktop computer for 10 minute sessions. However, it becomes apparent that these short duration data collection times may not be an accurate representation of how people interact with mobile technology over extended periods of time.

Therefore, the purpose of this study was to measure upper extremity kinematics and muscle activity when using mobile devices over long durations of time in both healthy and subclinical NP populations.

3.0 METHODS

3.1 Study Participants

18 UOIT students (10 healthy participants with no NP during the last 6 months [5 females and 5 males] and 8 subclinical NP participants who have had NP within the last 12 months [5 females and 3 males]) participated. See table 1 for participant demographics. As a requirement to participate in this study, participants must have owned a laptop and regularly use the device constantly for a minimum of two hours. The subclinical NP criteria was NP for the past 12 months, which did not have to be chronic and pain which the individual had not yet sought medical treatment. In addition, participants must have owned a smartphone, which they use to text message, access the internet and play games regularly for a minimum of half an hour. This study was approved by the Research Ethics Board at the University Of Ontario Institute Of Technology.

Table 1: Mean age, weight and height (\pm standard deviation) of the 18 participants grouped and separated per condition (subclinical NP or healthy).

Population	Age (years)	Weight (kg)	Height (m)
Healthy Females (n = 5)	26.2 \pm 6.5	59.8 \pm 6.1	1.6 \pm 0.05
NP Females (n = 5)	23.2 \pm 2.4	66.0 \pm 9.3	1.6 \pm 0.05
Healthy Males (n = 5)	22.0 \pm 2.2	92.5 \pm 14.9	1.8 \pm 0.08
NP Males (n = 3)	25.3 \pm 4.7	95.9 \pm 17.0	1.8 \pm 0.08

3.2 Data Collection (Laptop and Smartphone Tasks)

Various laptop and smartphone tasks were completed by each participant in a randomized order. Each participant visited the Neuromechanics Laboratory twice, once to complete the laptop tasks and a second visit to complete the smartphone tasks. This allowed participants to rest between data collection trials. No direction was provided to the participants to stop using their devices between data collection days.

1. *Laptop Tasks*: The duration of the laptop tasks was one hour. Twenty minutes was devoted to typing, reading, and internet browsing (mouse use). The order of each 20 minute task was randomized for each participant. At the beginning of the session, participants were setup at a desk and chair similar to those used in classes (details below).
2. *Smartphone Tasks*: The duration of the smartphone tasks was 30 minutes. The 30 minute data collection time was divided into three predetermined randomized tasks. Ten minutes was devoted each to text messaging, playing a game and navigating the Internet without video watching. The investigator notified the participant when and what task they were to complete. Individuals were set up at the same desk and chair used for the laptop condition.

3.3 Experimental Procedures

Upon arrival to the lab, participants completed the consent form (Appendix A1) and three self-administered questionnaires, including:

1. *Frequency and Usage of Mobile Device Questionnaire (Appendix B1)*: This questionnaire was developed in part by the researchers of this thesis and by Korpinen et al., 2009. It provides information about each participant's laptop computer and smartphone as well as duration and frequency of use. The questionnaire asks about the mobile device brand which allowed for device weight and screen dimensions to be determined (see Appendix B2 for questionnaire results).
2. *The Neck Disability Index Questionnaire (Appendix B3)*: The neck disability index (NDI) questionnaire gathered information about symptoms of NP and the impact of NP on activities of daily living, including both work and lifestyle activities. Item content of NDI assesses various levels of NP, headache, personal care, work, driving, lifting, recreational activities, reading, sleeping, and concentration with each item including six possible responses each representing

increasing levels of disability. The NDI is scored in a similar way to the Oswestry Low Back Disability Index (ODI). Each item has an ordinal response scale with six potential responses, each describing a greater degree of disability, ranging from 0 to 5. Scores are summed to provide a total score ranging from 0 (no disability) to 50 (maximum disability) (Vernon & Mior, 1991). The NDI's total percentage score can be found by multiplying the total summed score by two and expressing the result as a percentage (Hains et al., 1998). Clinical significance of NDI scores has been reported: 0-4 (0-8%) no neck pain, 5 - 14 (8 – 28%) mild neck pain, 15 – 24 (28 – 48%) moderate neck pain, 25 – 34 (48 – 68%) severe neck pain, and > 35 (>68%) complete neck pain (Vernon & Mior, 1991). See Appendix D1 for validity and reliability of this questionnaire.

3. *Chronic Pain Grade Scale (Appendix B4)*: This questionnaire was used to classify chronic pain of all participants based on the pain characteristic and how it impacts their daily activities.

3.3.1 Muscle activity:

Next, muscle activity was monitored using a wireless electromyography (EMG) system (Trigno™, Delsys Inc., Boston, MA, USA). Six wireless surface electromyography (SEMG) sensors with parallel bar electrodes separated by a fixed 10 mm inter-electrode distance were used to record, bilaterally from the following muscles: 1) upper trapezius, 2) cervical extensors, and 3) anterior deltoid. The Common Mode Rejection Ratio for the system was 92 dB at 60 Hz with an Input Impedance of 10 Ω (Delsys Inc., Boston, MA, United States). All signals were band-pass filtered (20-450 Hz), amplified (Trigno™, Delsys Inc., Boston, MA, United States) and sampled at a rate of 2000 Hz with a 16 bit analog to digital converter (3D Investigator Data Acquisition Unit, Northern Digital Inc., Waterloo, ON, Canada). Prior to electrode placement, standard skin preparations which included shaving the surface of the skin with a disposable razor and cleansing the skin with alcohol swabs was performed. Electrodes

were placed over the midline of each muscle-belly and in-line with the muscle fiber direction. Next, muscle specific maximal voluntary contractions (MVCs) were conducted and later used to normalize the muscle activity from data collection trials as a percentage of maximal voluntary excitation (%MVE). Muscle specific maximal contractions were performed once for each muscle to determine the maximum muscle activity during a five second isometric contraction. The neck MVC was performed while the participant was sitting with a straight back in a steady chair. The researcher provided resistance against the back of the participant's head, as the participant tried to extend. The upper trapezius MVC was completed while participants sat in a sturdy chair with their arms hanging loosely at their sides. The researcher grasped the participants' wrists and provided a pulling force attempting to pull their arm downwards towards the floor. The participants were instructed to counter this force as hard as they could by shrugging their shoulder upwards to activate the upper trapezius. The anterior deltoid MVC included the participant sitting in a sturdy chair, upper arm flexed to 90° and a slight bend at the elbow. The researcher placed a downward force against the participants' wrist while the participants were instructed to generate a maximal shoulder flexion movement.

3.3.2 Heart rate and chest motion sensor:

An EKG sensor with two snap leads was placed on the subject's left and right anterior chest. Both leads were attached to disposable, pre-gelled, Ag-AgCl surface electrodes (Meditrace™ 130 ECG, Kendall, MA, USA). The accelerometer within the EKG sensor was placed in the middle of the subject's chest with double sided adhesive. The EKG sensor was collected with the same technical specifications as the EMG and was synchronized with the EMG data. The accelerometer was used to monitor chest movements with an X, Y, and Z coordinate system (see figure 1). Chest movements determined

breathing rate during the experiment. All subjects conducted a resting EKG, breathing, and SEMG trial for 10 seconds prior to data collection.

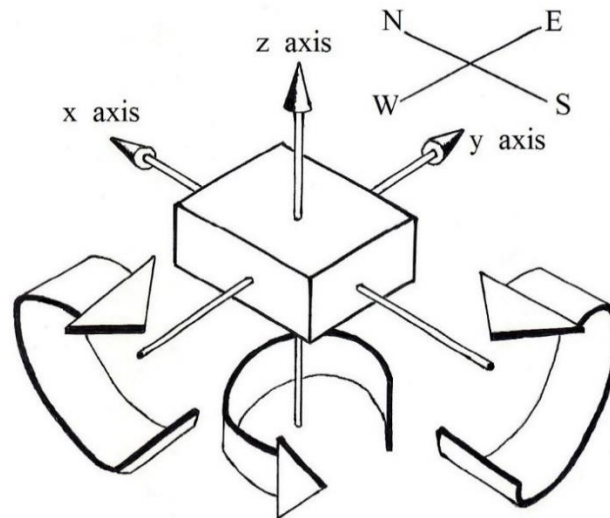


Figure 1: X, Y, and Z coordinate system of the accelerometer within all SEMG and EKG sensors. The directional compass illustrates the top (N) and bottom (S) of the sensor. The top of the sensor was always placed on the participants facing up.

3.3.3 Three Dimensional Kinematics:

Custom made rigid bodies were placed on the thorax and head of each participant. The rigid bodies consisted of 3 or more light emitting infrared markers such that the three dimensional orientation and position of each segment could be tracked. Five micro sensors were attached using medical tape to the skin overlaying the last five cervical spinous processes (C3 to C7). See Figure 2 for camera and sensor placements. Lastly, two micro sensors were placed on one side of the mobile device to track screen tilt in relation to the head (Figures 3 and 4). Kinematics were collected using motion capture (3D Investigator, Northern Digital Inc., Waterloo, ON, Canada). Bony prominences were digitized and all kinematics were collected at 128 Hz (see table 2) and synchronized with the EMG and heart rate data.

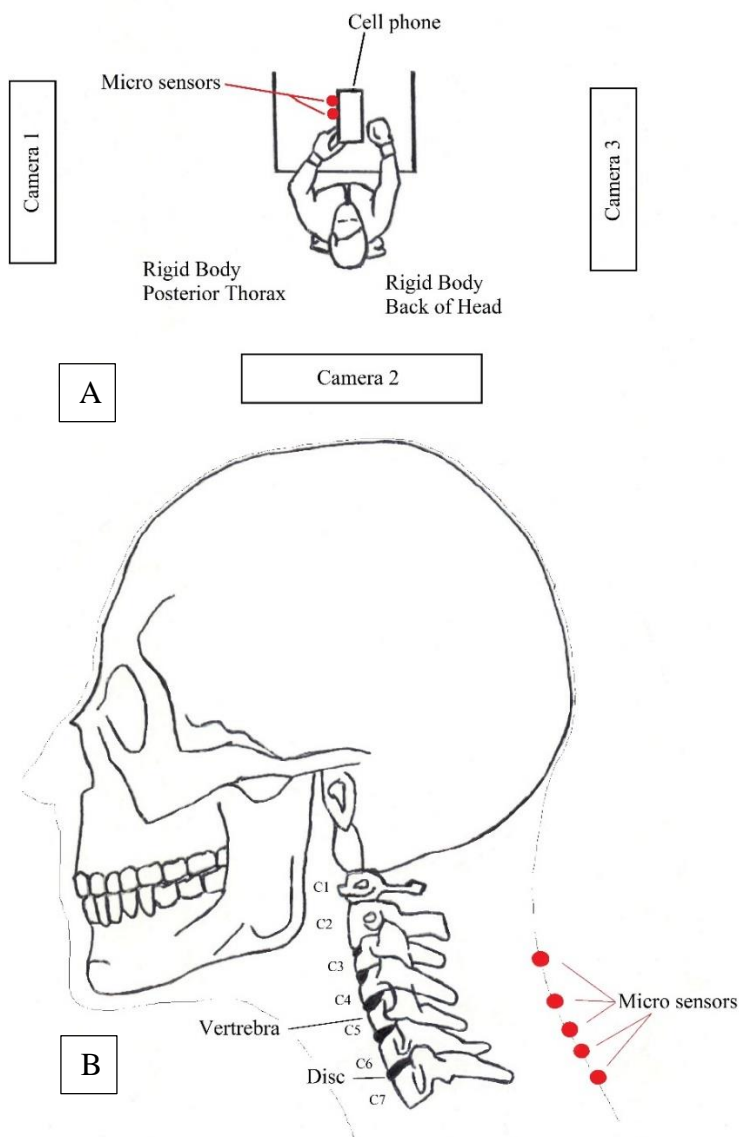


Figure 2: Setup of motion capture cameras and sensors for all participants and all tasks. A) Illustrates the camera placement, participant placement and micro sensor placement on the smartphone. B) Illustrates the placement of the five micro sensors over the participants' skin above the five spinous processes of C3 to C7.

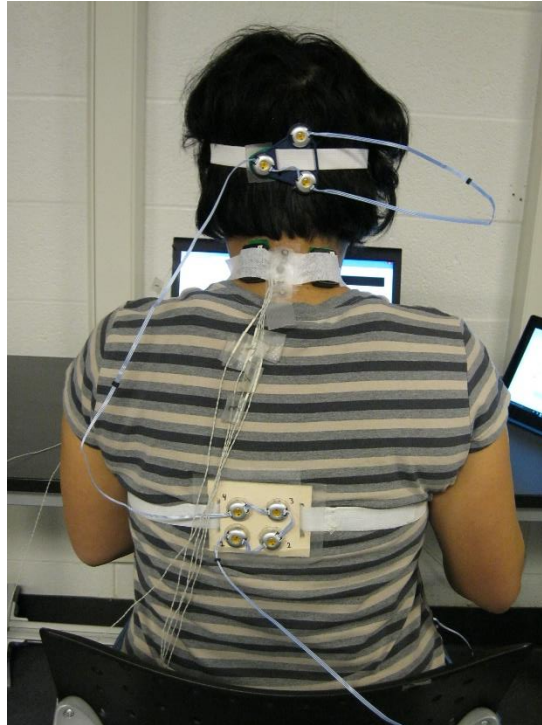


Figure 3: Placement of the head and thorax rigid bodies.



Figure 4: Placement of the micro sensors on a laptop computer along with the tablet computer that was used to collect discomfort score data.

Table 2: Two rigid bodies and the digitized bony prominences for each participant.

Segment	Proximal Digitized Locations		Distal Digitized Locations	
	Lateral	Medial	Lateral	Medial
Head	Right Mastoid	Left Mastoid	Right Top of Head	Left Top of Head
Thorax	Right Iliac Crest	Left Iliac Crest	Right Acromion	Left Acromion

A static calibration (resting) trial was collected for five seconds. The participant sat with their feet flat on the floor, head and eyes facing forward, with forearms and palms of hands facing anteriorly at the sides.

3.3.4 Discomfort: Rating of Perceived Discomfort Questionnaire (Appendix B5):

This questionnaire used Likert scales from 0 to 100 mm and a diagram of the upper body divided into bilateral sections (see figure 5). This questionnaire is adapted from a previous study who used a Rating of Perceived joint discomfort when observing sitting and standing (Genaidy & Karwowski, 1993). This questionnaire was administered every 10 minutes during the laptop condition and every 5 minutes during the smartphone condition. A custom made program (MatLab 2015a, Natick, MA) was used via a touch screen device, such that the user could easily select discomfort levels.

DiscomfortGUI3

Body Region Discomfort Questionnaire

To answer each question move the slider to the corresponding location

	No Discomfort		Extreme Discomfort
1	0	<input type="range"/>	100
2	0	<input type="range"/>	100
3	0	<input type="range"/>	100
4	0	<input type="range"/>	100
5	0	<input type="range"/>	100
6	0	<input type="range"/>	100
7	0	<input type="range"/>	100
8	0	<input type="range"/>	100

The number displayed in the regions in the diagram above correspond with the numbers in the survey to the right of the diagram

Save

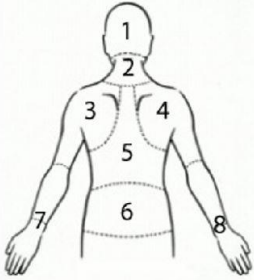


Figure 5: Discomfort scale used at regular intervals (10 minutes during the laptop computer tasks and every 5 minutes during the smartphone tasks).

3.4 Data Analysis:

Kinematic data was filtered using a second order, dual pass Butterworth low pass filter, with a cutoff frequency of 6Hz in Visual 3D V5 (C-Motion, Inc., Germatown, MD). Anatomical frames of reference were derived from the digitized landmarks to determine cervical joint kinematics throughout the laptop and smartphone tasks. All kinematic data were processed using an X (flexion/extension), Y (medial/lateral), Z (twist) rotation sequence. The amplitude probability distribution function (APDF; Jonsson, 1978) was used to determine the percentage of time spent in each posture during the duration of each task. The APDFs were calculated for each five minute interval for the smartphone task and each ten minute interval for the laptop tasks. The APDF was calculated to give the 10th, 50th, and 90th percentiles for neck flexion, lateral bend and rotation.

All SEMG data was full-wave rectified, Butterworth low-pass filtered (2nd order, dual pass, 3 Hz cut-off) and normalized to the previously collected maximal voluntary contractions (Matlab 2014,

Natick, MA). For all normalized data for each task, the APDF was calculated to give the 10th, 50th, and 90th percentiles of muscle activity for each muscle. The 10th, 50th, and 90th percentiles of the APDF were calculated to represent measures of low level muscle activity, median level, and peak muscle activity (Jonsson, 1978). To determine the amount of myoelectric rest for each muscle, EMG gaps were calculated as the total time (within each collection sample) that EMG was less than or equal to 2% MVE for at least 0.2 s. The gaps analysis determined the number of gaps, the average gap time in seconds and the standard deviation.

Microsoft Excel 2013 was used to analyze both heart rate and chest movements. Averages in five minute intervals were taken of the EKG data to determine if there were any fluctuations in the voltages which would signify a change in the heart rate during the different tasks. The X, Y, and Z axis of the accelerometer was used to determine chest expansion and contraction during breathing.

Discomfort scores were collected on a 100 millimeter scale and normalized to baseline by subtracting all values during data collection from each participant's baseline measurements. Discomfort values are graphed within the results section with time intervals along the x-axis (Baseline represents 0 minutes). The time intervals are dependent of the mobile device being use. The laptop condition time intervals increased by 10 minutes each while the smartphone condition time intervals increased by 5 minutes each.

3.4.1 Gaze angle calculations:

Gaze angles were calculated by using the averages of the X, Y and Z coordinates of the left digitized point of the eye and the X, Y and Z coordinates of the superior micro sensor that was placed on the mobile device. Two vectors were calculated. The first was calculated by subtracting the two y coordinates of the left eye digitized point from the superior micro sensor. The second vector was

determined by subtracting the two z coordinates of the left eye digitized point and the superior micro sensor on the mobile device. Trigonometry was used to determine gaze angle (Figure 6).

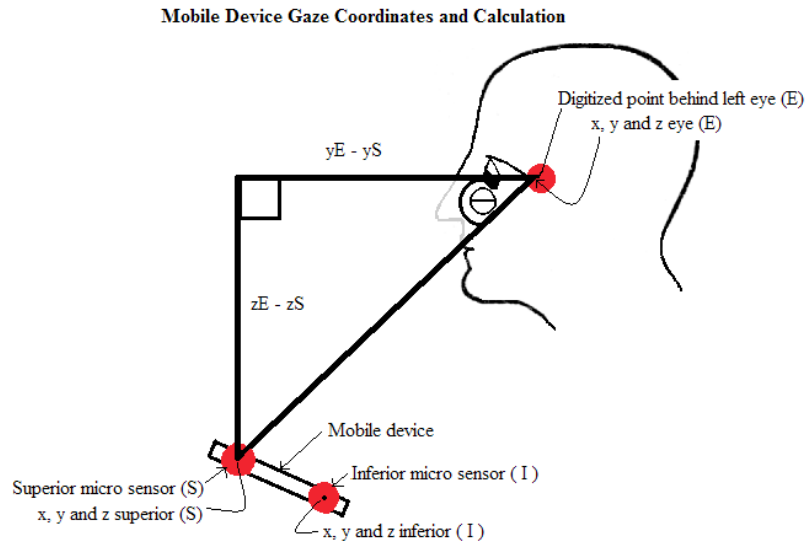


Figure 6: How the gaze angles were calculated for all participants.

3.4.2 Statistical analysis:

A Repeated Measures ANOVA was used to determine differences between groups for the kinematic APDF data, EMG APDF and gaps data, and the discomfort score data (SPSS, V23, IBM Corporation, Armonk, New York). A mixed analysis of variance (ANOVA) with six within factors (time interval [1-6]) and two between factors (group [pain vs. no pain] and sex [male and female]) was used to test the effects on muscle activity (APDFs, gaps), kinematics (APDFs) and each of the 8 perceived discomfort locations. Each dependent EMG variable (10th, 50th, 90th percentiles and gaps) was tested separately for each muscle. When statistical main and interaction effects were found, a Bonferroni correction post-hoc analysis was conducted. Statistical significance was set at a $P < 0.05$.

4.0 RESULTS

4.1 Device Characteristics

Appendix B2 illustrates the dimensions and types of mobile devices that were used by the participants in each group. Averaged across all groups, the average smartphone size, screen size and weight were 134.7 mm x 67.1 mm x 8.5 mm, 119.3 mm, and 90.7 grams, respectively. Averaged across all groups, the average laptop size, screen size and weight were 66.4 mm x 133.6 mm x 353.1 mm, 355.6 mm, and 2.0 kilograms, respectively (see Appendix B2).

4.2 Questionnaires

4.2.1 The Neck Disability Index and Grading the Severity of Chronic Pain Questionnaires (Appendices B3 and B4, respectively): Please see Appendix B2 for the results of the individual responses to the Grading of the Severity of Chronic Pain Questionnaire.

4.2.2 Participant Characteristics: The NP characteristics for the healthy and NP groups can be found in Table 3. The average NDI scores were 1.6% (no disability) for healthy males and 2.8% (no disability) for healthy females. The average NDI scores were 21.3% (moderate disability) for NP males and 18.4% (moderate disability) for NP females. Healthy males and females had a Chronic Pain Grade Scale of 0 (pain free). NP males had a Chronic Pain Grade Scale of 1 (low disability and low intensity) and NP females were 1.2 (low disability and low intensity). There was a significant difference between NDI pain scores for the two groups ($p = 0.028$). There was no significant difference between the Chronic Pain Grade Scale classification of the two groups ($p = 0.058$). These two p values were calculated using a paired t -test.

Table 3: Healthy and subclinical NP scores for the two groups based on two NP questionnaires (NDI / Chronic Pain Grade Scale classification).

Healthy Females	NP Females	Healthy Males	NP Males
2.8% (no disability) / 0 (pain free)	18.4% (moderate disability) / 1.2 (low disability and low intensity)	1.60 (no disability) / 0 (pain free)	21.3 (moderate disability) / 1 (low disability and low intensity)

4.3 Laptop

4.3.1 Discomfort Scores

4.3.1.1 Posterior Neck

The posterior neck had a significant main effect of time ($F_{5,70} = 40.304$, $P = 0.000$). Baseline (0 minutes) was significantly less than 20 minutes ($p = 0.001$, $6.2 \text{ mm} \pm 1.1 \text{ mm}$) and 50 minutes ($p = 0.031$, $7.4 \text{ mm} \pm 2.0 \text{ mm}$). There was also a significant main effect of group ($F_{5,70} = 5.599$, $P = 0.033$), where the healthy participants had a lower mean score ($5.8 \text{ mm} \pm 1.9 \text{ mm}$) than the subclinical NP participants ($12.7 \text{ mm} \pm 12.7 \text{ mm}$). There was also a significant sex by group interaction ($F_{5,70} = 7.982$, $P = 0.013$), where healthy females ($6.9 \text{ mm} \pm 2.7 \text{ mm}$) had a higher score than the subclinical females ($5.5 \text{ mm} \pm 2.7 \text{ mm}$). Healthy males had a lower score ($4.7 \text{ mm} \pm 2.7 \text{ mm}$) than the subclinical males ($19.8 \text{ mm} \pm 3.5 \text{ mm}$) (Figure 7 B).

Discomfort during the last 12 months prior to data collection were also reported within the Frequency and Usage of Mobile Device Questionnaire. Two of the five healthy female participants responded with experiencing aches, pain or numbness to their neck when using their laptop computers. All female NP participants reported having aches, pain or numbness in their neck when using their laptop computer. Three of the five healthy males associated an ache, pain or numbness in their necks when using their laptop computer. All male NP participants associated aches, pain or numbness to their neck when using their laptop computer. (See Appendix B2 for all comparisons).

4.3.1.2 *Posterior Left Shoulder*

The posterior left shoulder demonstrated a sex by time by group interaction ($F_{5,70} = 3.491$, $P = 0.007$) (Figure 7 C). This finding suggests as time progressed, the discomfort scores across sex and group changed. Males had a higher mean score ($2.1 \text{ mm} \pm 1.4 \text{ mm}$) than females ($1.2 \text{ mm} \pm 1.2 \text{ mm}$). The healthy group had a higher mean score ($2.3 \text{ mm} \pm 1.2 \text{ mm}$) than the subclinical NP group ($1.0 \text{ mm} \pm 1.4 \text{ mm}$). The 30 minute interval had the lowest mean score ($0.8 \text{ mm} \pm 0.9 \text{ mm}$) than the other time intervals, 10 minutes ($0.8 \text{ mm} \pm 0.6 \text{ mm}$), 20 minutes ($2.6 \text{ mm} \pm 1.3 \text{ mm}$), 40 minutes ($1.1 \text{ mm} \pm 0.1 \text{ mm}$), 50 minutes ($2.4 \text{ mm} \pm 1.2 \text{ mm}$) and 60 minutes ($2.3 \text{ mm} \pm 1.3 \text{ mm}$).

Frequency usage questionnaire for the posterior shoulders were reported as the following: Four of the five healthy female participants responded by having an ache, pain or numbness sometimes in their shoulders when using their laptop computers. Five out of five subclinical females reported an ache, pain or numbness in their shoulders when using their laptop computer. Three of the five healthy males associated an ache, pain or numbness in their shoulders when using their laptop computer. Two of the three subclinical NP males associated an ache, pain or numbness in their shoulders with using their laptop computer.

4.3.2 *Surface Electromyography*

4.3.2.1 *APDF – 90th percentile*

For the left CE, females had a mean muscle activity of $14.9 \pm 6.5\%$ MVE while males had a mean of $12.9 \pm 7.5\%$ MVE. The healthy group had a mean of $17.8 \pm 6.5\%$ MVE while the NP group had a mean of $18.5 \pm 7.5\%$ MVE. For the right CE, females had a mean muscle activity of $24.6 \pm 5.3\%$ MVE while males had a mean of $12.3 \pm 6.1\%$ MVE. Healthy participants had a mean of $17.5 \pm 5.3\%$ MVE while subclinical NP participants had a mean of $19.3 \pm 6.1\%$ MVE. For the left UT, there was a

significant main effect for sex ($P=0.050$, $F_{1,14} = 4.579$), where females had a mean muscle activity of $16.4 \pm 4.3\%$ MVE while males had a mean of $2.3 \pm 4.9\%$ MVE. Healthy participants had a mean of $13.9 \pm 4.3\%$ MVE while subclinical NP participants had a mean of $5.4 \pm 4.9\%$ MVE. For the right UT, females had a mean muscle activity of $14.0 \pm 4.8\%$ MVE while males had a mean of $3.1 \pm 5.6\%$ MVE. Healthy participants had a mean of $9.3 \pm 4.8\%$ MVE while subclinical NP participants had a mean of $7.8 \pm 5.6\%$ MVE. For the left AD, females had a mean muscle activity of $7.8 \pm 2.4\%$ MVE while males had a mean of $23.9 \pm 2.8\%$ MVE. Healthy participants had a mean of $4.5 \pm 2.4\%$ MVE while subclinical NP participants had a mean of $7.12 \pm 2.8\%$ MVE. For the right AD, females had a mean muscle activity of $2.7 \pm 0.7\%$ MVE while males had a mean of $2.4 \pm 0.8\%$ MVE. Healthy participants had a mean of $2.1 \pm 0.7\%$ MVE while subclinical NP participants had a mean of $3.1 \pm 0.8\%$ MVE (Figure 8).

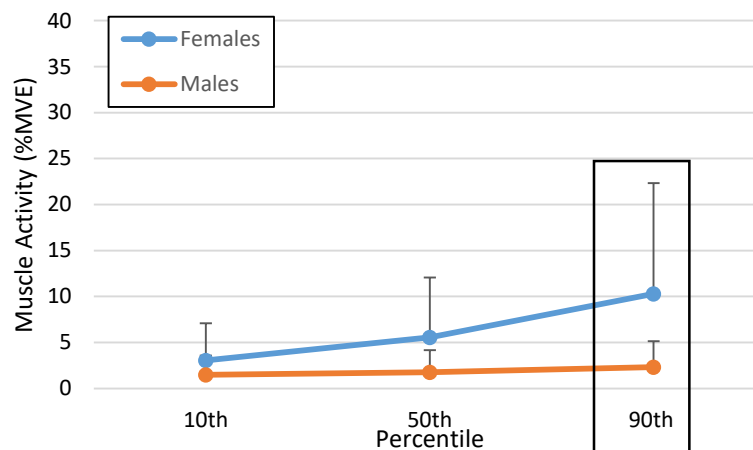


Figure 8: Left UT muscle activity (%MVE) for males and females for the 90th percentile APDF.

4.3.2.2 Gaps Analysis

There was a significant difference for the number of gaps for the right AD ($P=0.042$, $F_{1,14} = 5.001$), this is presented in Appendix C4.

4.3.3 Kinematics

Neck Flexion Angles

Neck flexion and extension angles are the focus of this section, since this is the most prominent neck posture and motion exhibited during long duration smartphone and laptop use. However, there were no significant differences found within the 10th, 50th or 90th percentiles for flexion between the groups (see Appendix C1). Despite this, like EMG, there appears to be differences between groups and thus, a descriptive analysis is demonstrated below. Further analysis may focus on lateral bend and twisting.

4.3.3.1 APDF - 10th percentile neck flexion

Females had a mean of $-2.8^{\circ} \pm 4.3^{\circ}$, while males had a mean of $2.5^{\circ} \pm 4.9^{\circ}$. Healthy participants had a mean of $-1.8^{\circ} \pm 4.2^{\circ}$, while subclinical NP participants had a mean of $1.5^{\circ} \pm 4.9^{\circ}$. Healthy females had a mean of $-7.2^{\circ} \pm 6.0^{\circ}$ and subclinical females had a mean of $1.5^{\circ} \pm 6.0^{\circ}$. Healthy males had a mean of $3.6^{\circ} \pm 6.0^{\circ}$, while subclinical males had a mean of $1.6^{\circ} \pm 7.7^{\circ}$.

4.3.3.2 APDF - 50th percentile neck flexion

Females had a mean of $2.9^{\circ} \pm 4.4^{\circ}$, while males had a mean of $5.9^{\circ} \pm 5.1^{\circ}$. Healthy participants had a mean of $3.1^{\circ} \pm 4.4^{\circ}$, while subclinical NP participants had a mean of $5.7^{\circ} \pm 5.1^{\circ}$. Healthy females had a mean of $-1.2^{\circ} \pm 6.2^{\circ}$ and subclinical females had a mean of $6.9^{\circ} \pm 6.2^{\circ}$. Healthy males had a mean of $7.3^{\circ} \pm 6.2^{\circ}$, while subclinical males had a mean of $4.5^{\circ} \pm 8.0^{\circ}$.

4.3.3.3 APDF - 90th percentile neck flexion

Females had a mean of $8.1^{\circ} \pm 4.5^{\circ}$, while males had a mean of $9.3^{\circ} \pm 5.2^{\circ}$. Healthy participants had a mean of $7.4^{\circ} \pm 4.5^{\circ}$, while subclinical NP participants had a mean of $10.0^{\circ} \pm 5.2^{\circ}$. Healthy females

had a mean of $4.1^{\circ} \pm 6.4^{\circ}$ and subclinical females had a mean of $12.1^{\circ} \pm 6.4^{\circ}$. Healthy males had a mean of $10.7^{\circ} \pm 6.4^{\circ}$, while subclinical males had a mean of $7.9^{\circ} \pm 8.2^{\circ}$.

In all three percentiles, healthy females continuously have lower head flexion and extension angles when compared to healthy males. The healthy male results fell within the ranges of the head and neck flexion angles of the subclinical NP females and males. This can be observed in the figures presented in Appendix C1.

4.4 Smartphone

4.4.1 Discomfort Scores

4.4.1.1 Posterior Left Shoulder

The posterior left shoulder demonstrated a sex by time by group interaction ($F_{5,70} = 3.491$, $P = 0.007$). Females had slightly higher mean scores ($1.5 \text{ mm} \pm 0.8 \text{ mm}$) than males ($1.3 \text{ mm} \pm 0.9 \text{ mm}$). Healthy participants' mean discomfort scores were much higher ($2.3 \text{ mm} \pm 0.8 \text{ mm}$) compared to subclinical NP participants ($0.5 \text{ mm} \pm 0.9 \text{ mm}$). Healthy females had higher mean discomfort score ($2.5 \text{ mm} \pm 1.2 \text{ mm}$) when compared to subclinical females ($0.5 \text{ mm} \pm 1.2 \text{ mm}$), healthy males ($2.0 \text{ mm} \pm 1.2 \text{ mm}$) and subclinical NP males ($0.5 \text{ mm} \pm 1.5 \text{ mm}$). As time progressed, the mean discomfort scores varied from high to low during the 30 minute data collection. The first 5 minutes had a mean score of ($0.6 \text{ mm} \pm 0.4 \text{ mm}$), 10 minutes ($1.7 \text{ mm} \pm 0.9 \text{ mm}$), 15 minutes ($1.3 \text{ mm} \pm 0.8 \text{ mm}$), 20 minutes ($0.9 \text{ mm} \pm 0.7 \text{ mm}$), 25 minutes ($1.3 \text{ mm} \pm 0.7 \text{ mm}$) and 30 minutes ($2.7 \text{ mm} \pm 1.1 \text{ mm}$) (see Figure 9 E).

Frequency usage questionnaire for the posterior shoulders were reported as the following: Two of the five healthy females reported an ache, pain or numbness within their shoulders with smartphone use. Three out of five of the subclinical NP females reported an ache, pain or numbness within their shoulders that they associated with smartphone use. Three of the five healthy males associated an ache,

pain or numbness within their shoulders with smartphone use. All three subclinical NP males reported an ache, pain or numbness in their shoulders associated with smartphone use.

4.4.1.2 Posterior Right Shoulder

The posterior right shoulder demonstrated a sex by time significant difference ($P = 0.011$), with females having greater mean scores ($1.3 \text{ mm} \pm 0.5 \text{ mm}$) than males ($1.1 \text{ mm} \pm 0.6 \text{ mm}$) (Figure 9 F).

4.4.2 Surface Electromyography

4.4.2.1 APDF – 50th percentile

There was a significant sex by group interaction ($P = 0.023$, $F_{1,14} = 6.552$) for the left CE (Figure 10).

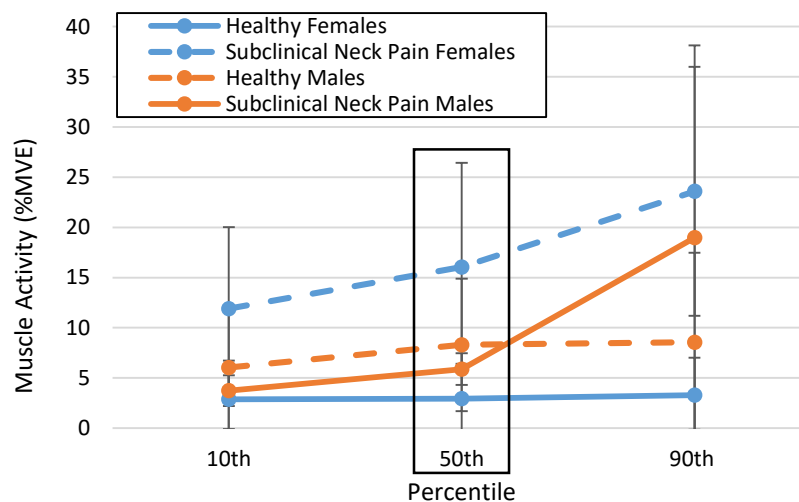


Figure 10: Left CE muscle activity (%MVE) for healthy and subclinical NP participants, illustrating the sex by group interaction for the 50th percentile APDF.

Females had a mean muscle activity of $9.5 \pm 2.0\%$ MVE while males had a mean of $7.1 \pm 2.3\%$ MVE. Healthy participants had a mean muscle activity of $25.6 \pm 2.0\%$ MVE while subclinical NP participants had a mean of $11.0 \pm 2.3\%$ MVE. For the right CE, females had a mean muscle activity of

$10.5 \pm 2.2\%$ MVE while males had a mean of $6.8 \pm 2.6\%$ MVE. Healthy participants had a mean muscle activity of $9.0 \pm 2.2\%$ MVE while subclinical NP participants had a mean of $8.3 \pm 2.6\%$ MVE. For the left UT, females had a mean muscle activity of $7.1 \pm 2.7\%$ MVE while males had a mean of $1.1 \pm 3.1\%$ MVE. Healthy participants had a mean muscle activity of $3.1 \pm 2.7\%$ MVE while subclinical NP participants had a mean of $5.1 \pm 3.1\%$ MVE. For the right UT, females had a mean muscle activity of $7.8 \pm 2.8\%$ MVE while males had a mean of $2.4 \pm 3.2\%$ MVE. Healthy participants had a mean muscle activity of $3.7 \pm 2.8\%$ MVE while subclinical NP participants had a mean of $6.5 \pm 3.2\%$ MVE.

4.4.2.2 APDF – 90th percentile

There was a significant main effect of group ($P=0.014$, $F_{1,14}=7.968$) for the left CE (Figure 11).

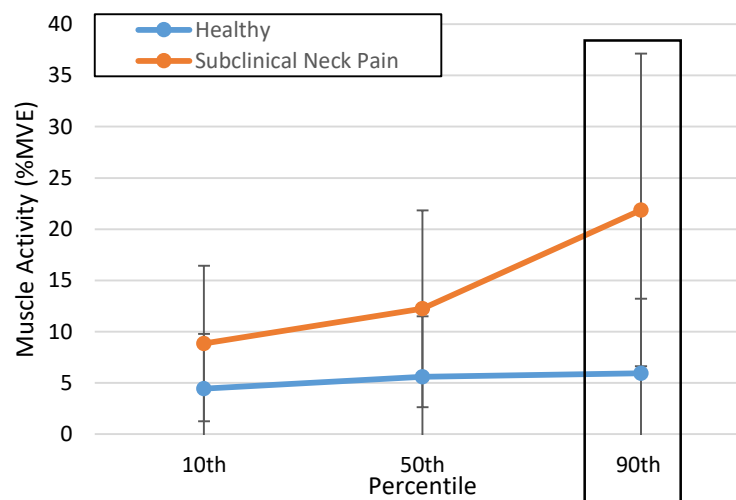


Figure 11: Left CE muscle activity (%MVE) for healthy and subclinical NP participants for the 90th percentile APDF.

Females had a mean muscle activity of $13.4 \pm 3.6\%$ MVE while males had a mean of $13.8 \pm 4.1\%$ MVE. Healthy participants had lower muscle activity 5.9 ± 3.6 than N.P. 21.3 ± 4.1 . For the right CE, females had a mean muscle activity of $14.1 \pm 2.9\%$ MVE while males had a mean of $7.8 \pm 3.3\%$

MVE. Healthy participants had a mean muscle activity of $11.4 \pm 2.9\%$ MVE while subclinical NP participants had a mean of $10.5 \pm 3.3\%$ MVE. For the left UT, females had a mean of $8.3 \pm 3.4\%$ MVE while males had a mean of $4.1 \pm 3.9\%$ MVE. Healthy participants had a mean muscle activity of $3.3 \pm 3.4\%$ MVE while subclinical NP participants had a mean of $9.0 \pm 3.9\%$ MVE. For the right UT, females had a mean of $10.2 \pm 3.3\%$ MVE while males had a mean of $2.8 \pm 3.8\%$ MVE. Healthy participants had a mean muscle activity of $5.1 \pm 3.3\%$ MVE while subclinical NP participants had a mean of $7.9 \pm 3.8\%$ MVE.

4.4.2.3 Gaps Analysis

There were no significant differences found for the total gap time (seconds) for any of the muscles evaluated in this study.

For number of gaps, there was a significant sex by group interaction for the right CE ($P=0.043$, $F_{1,14} = 4.965$) with subclinical males having the highest number of gaps (36.1 ± 12.2), healthy males the least (0.30 ± 9.5). Healthy females (11.3 ± 9.5) had more gaps than subclinical females (1.5 ± 9.5) (Figure 12).

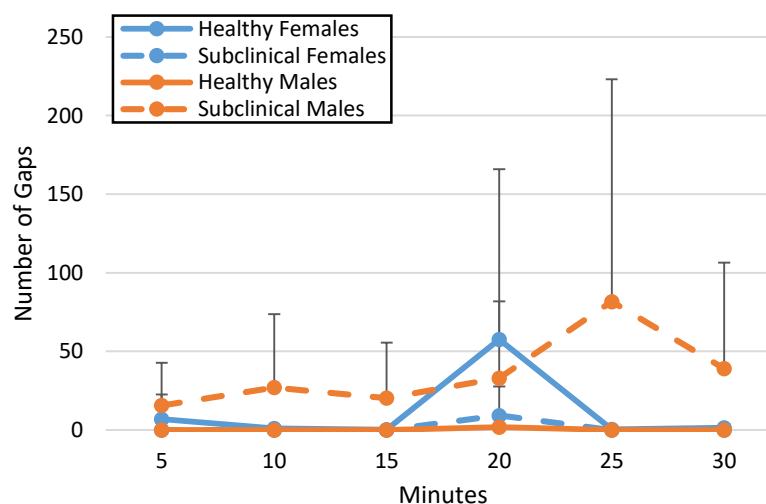


Figure 12: Number of gaps during the smartphone task for the right cervical extensor.

There was a significant main effect of sex for average gap time for the left UT ($P=0.019$, $F_{1,14}=7.041$). Males spent more time on average below the 2% threshold (118.0 ± 28.5 sec) than females (17.9 ± 24.7 sec) (Figure 13).

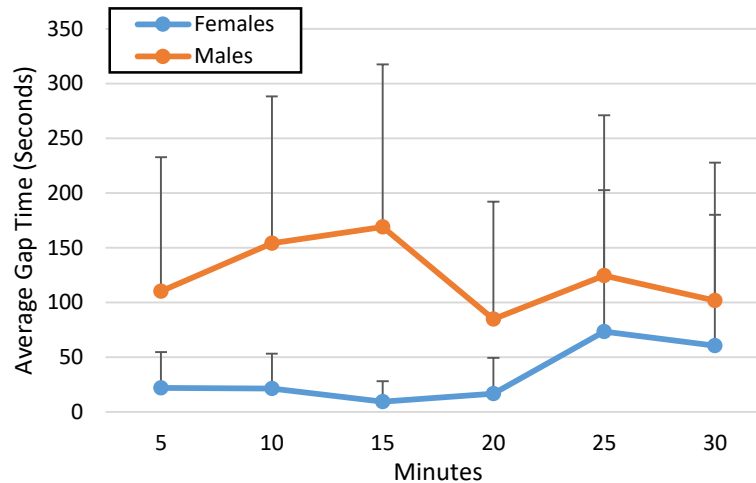


Figure 13: Average gap time (seconds) of females and males for the smartphone task of the upper trapezius.

4.4.3 Kinematics

Neck Flexion Angles

As stated above, neck flexion and extension angles are the focus of this section. However, there were no significant differences found within the 10th, 50th or 90th percentiles for flexion between the groups (see Appendix C1). Despite this, like EMG, there appears to be differences between groups and thus, a descriptive analysis is demonstrated below.

4.4.3.1 APDF - 10th percentile neck flexion

Females had a mean of $6.6^\circ \pm 4.5^\circ$ while males had a mean of $13.3^\circ \pm 5.2^\circ$. Healthy participants had a mean of $5.8^\circ \pm 4.5^\circ$, while subclinical NP participants had a mean of $14.0^\circ \pm 5.2^\circ$. Healthy females

had a mean of $-0.4^{\circ} \pm 6.4^{\circ}$ and subclinical females had a mean of $13.6^{\circ} \pm 6.4^{\circ}$. Healthy males had a mean of $12.0^{\circ} \pm 6.4^{\circ}$, while subclinical males had a mean of $14.5^{\circ} \pm 8.2^{\circ}$.

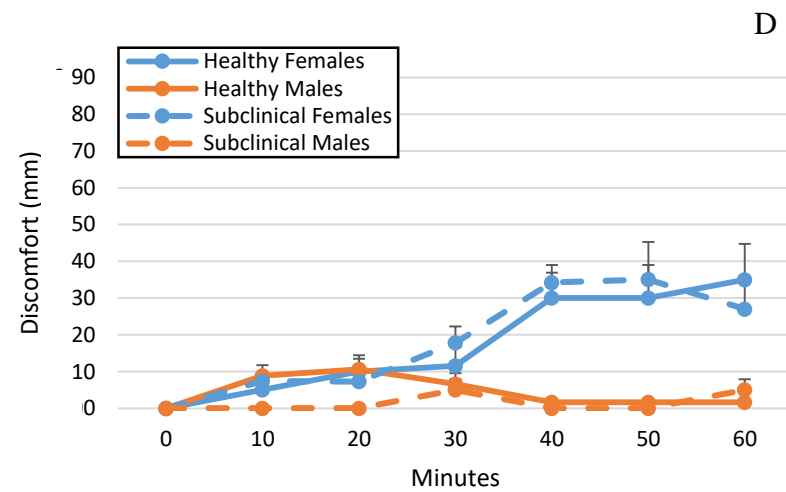
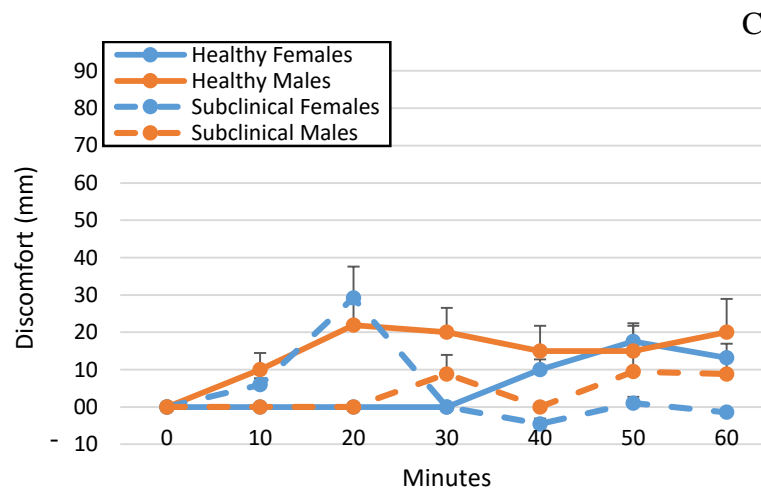
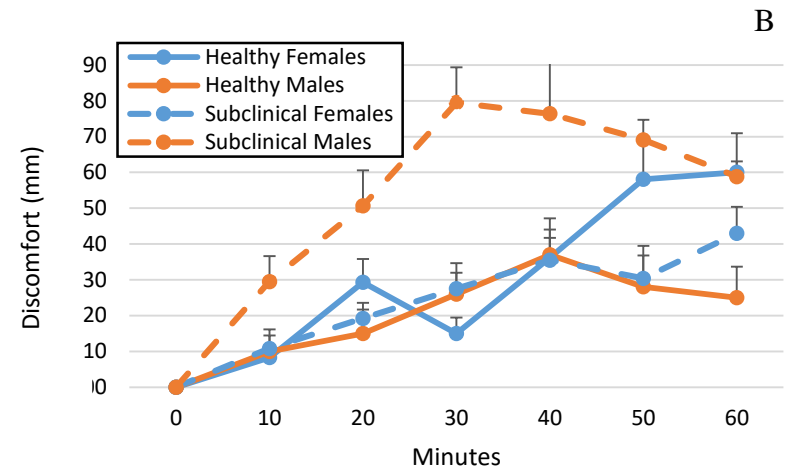
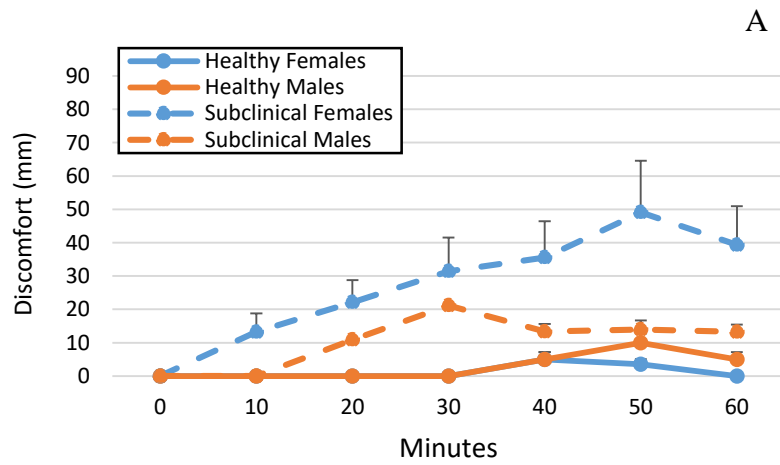
4.4.3.2 APDF - 50th percentile neck flexion

Females had a mean of $11.9 \pm 4.6^{\circ}$, while males had a mean of $16.9 \pm 5.4^{\circ}$. Healthy participants had a mean of $10.8 \pm 4.6^{\circ}$, while subclinical NP participants had a mean of $17.9 \pm 5.4^{\circ}$. Healthy females had a mean of $5.7 \pm 6.6^{\circ}$ and subclinical females had a mean of $18.0 \pm 6.6^{\circ}$. Healthy males had a mean of $15.9 \pm 6.6^{\circ}$, while subclinical males had a mean of $17.9 \pm 8.4^{\circ}$.

4.4.3.3 APDF - 90th percentile neck flexion

Females had a mean of $16.4^{\circ} \pm 4.8^{\circ}$, while males had a mean of $20.5^{\circ} \pm 5.6^{\circ}$. Healthy participants had a mean of $15.8^{\circ} \pm 4.8^{\circ}$, while subclinical NP participants had a mean of $21.4^{\circ} \pm 5.6^{\circ}$. Healthy females had a mean of $11.2^{\circ} \pm 6.8^{\circ}$ and subclinical females had a mean of $21.6^{\circ} \pm 6.8^{\circ}$. Healthy males had a mean of $19.8^{\circ} \pm 6.8^{\circ}$, while subclinical males had a mean of $21.3^{\circ} \pm 8.8^{\circ}$.

In all three percentiles, healthy females continuously have lower head flexion and extension angles when compared to healthy males. The healthy male results fell within the ranges of the head and neck flexion angles of the subclinical NP females and males. This can be observed in the figures presented in Appendix C1.



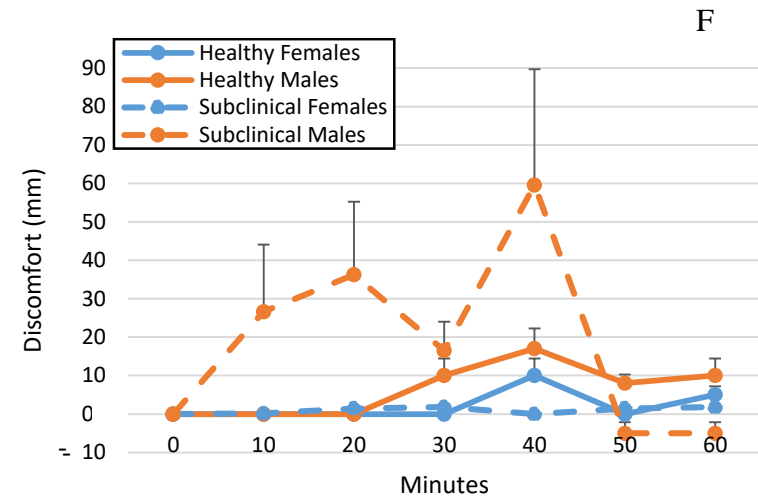
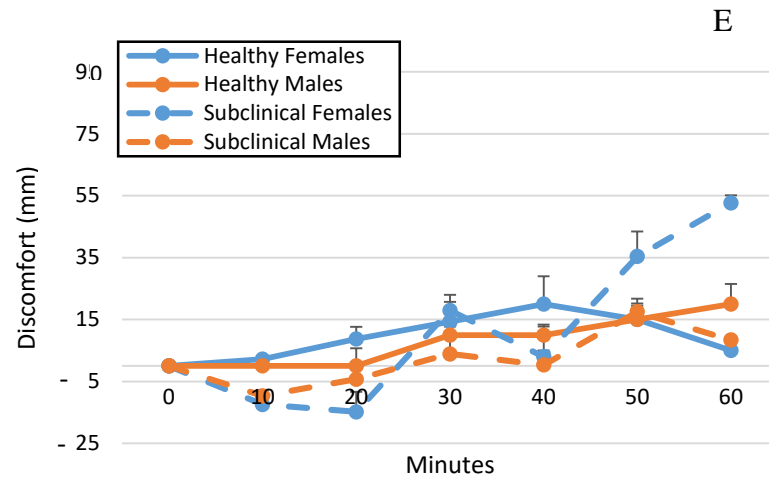
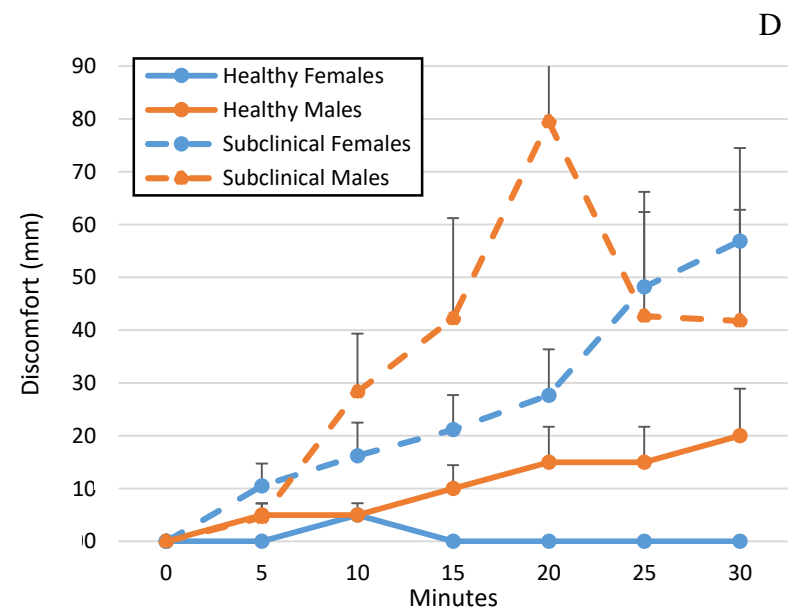
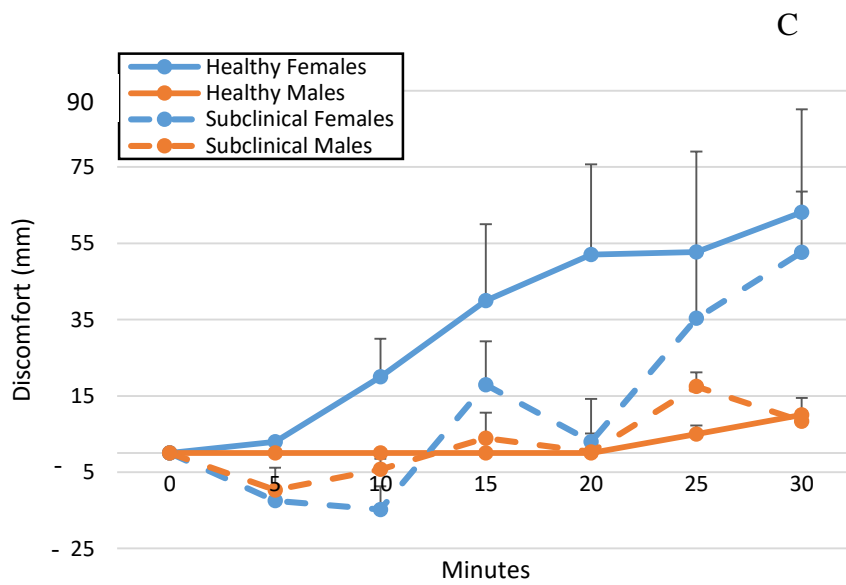
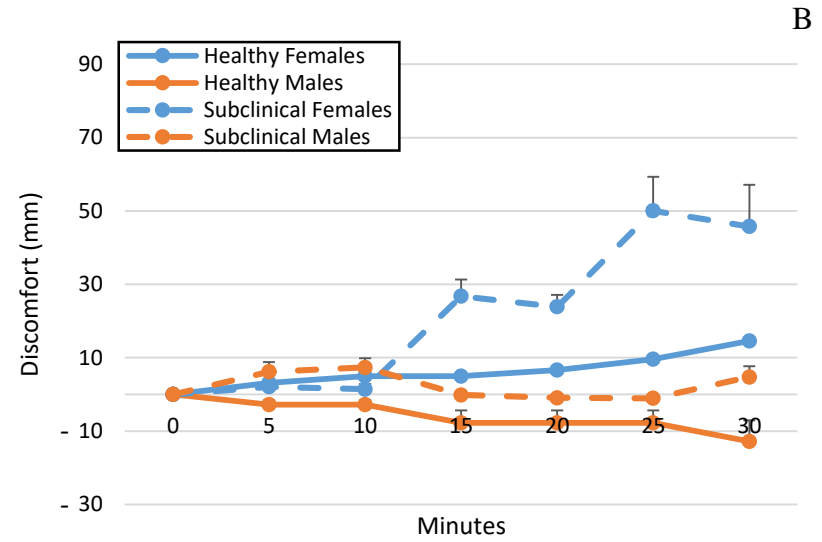
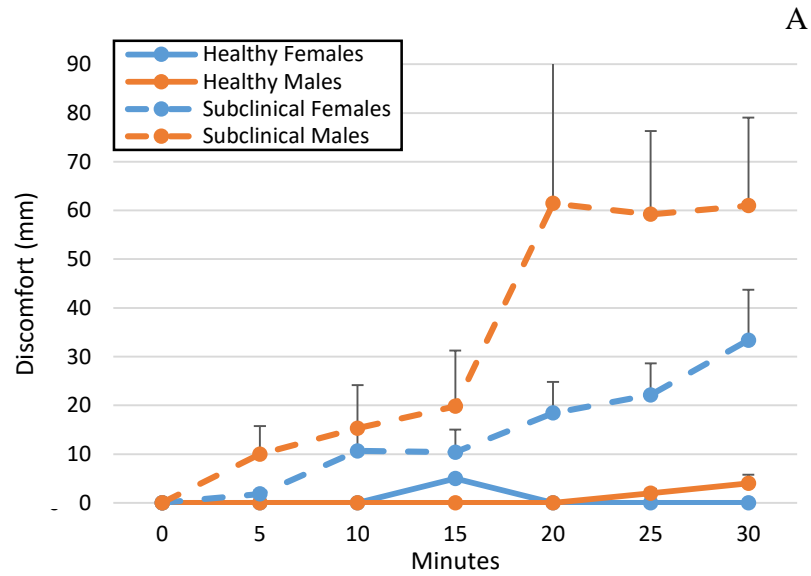


Figure 7: Discomfort scores (mm) for the posterior A) head, B) neck, C) shoulder, D) thoracic, E) lumbar/sacral and F) right hand during the 1 hour laptop task. Blue lines represent males, Red females. Solid lines healthy, dashed NP.



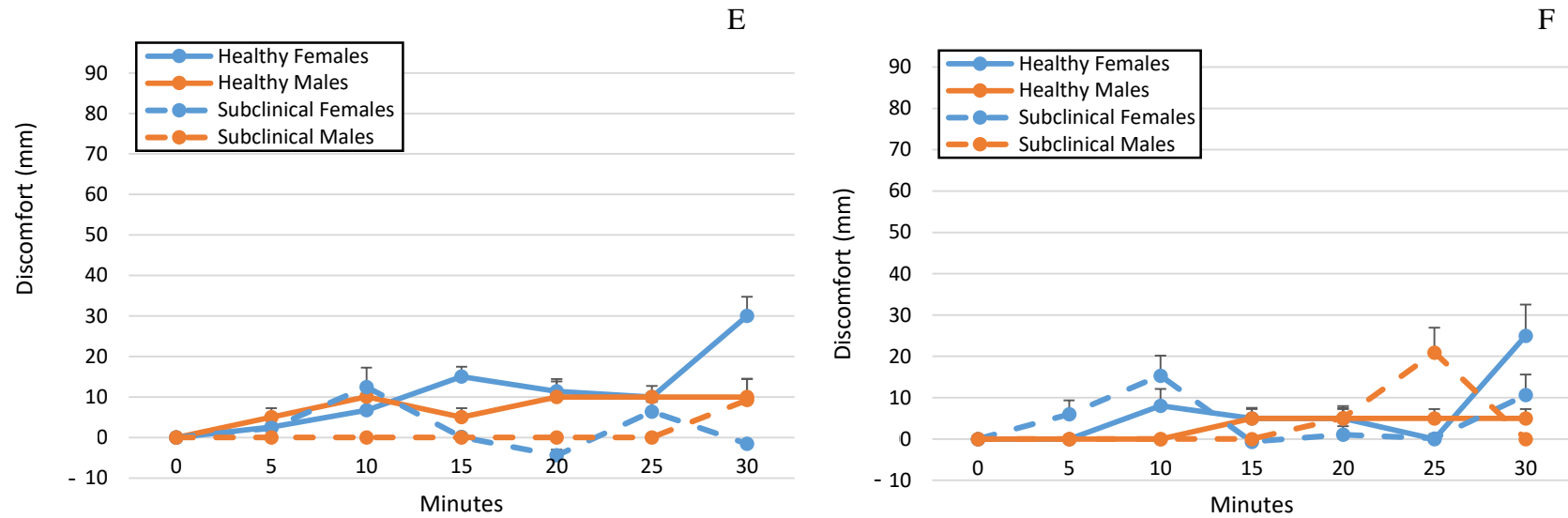


Figure 9: Discomfort scores (mm) for the posterior A) head, B) thoracic, C) lumbar/sacral, D) right hand, E) left shoulder and F) right shoulder during the half hour smartphone task. Blue represents females, Red represents males. Solid lines healthy, dashed NP.

4.5 Heart Rate and Chest Movements

Heart rate and chest movement voltages remained consistent across individuals during each task and no significant differences were found.

4.6 Gaze angles

The results are presented below in Table 4. Subclinical participants had more gaze angles that were greater than -45° (end limit of safe gaze angles suggested by ergonomic guidelines) than healthy participants (Straker et al., 2009).

Table 4: Smartphone and laptop group averages (displayed as Smartphone/Laptop).

Group	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6
Healthy Females	-6.7/24.2	-5.8/17.2	-23.6/16.5	-17.5/17.3	-21.6/15.4	1.5/16.8
Subclinical Females	-33.3/-1.0	-35.2/-3.8	-31.3/33.9	-33.9/-2.8	-34.8/-38.1	-33.7/-37.4
Healthy Males	-2.1/-28.4	0.6/-15.2	4.6/-15.8	-2.3/-16.6	-17.1/-14.5	-21.0/-24.9
Subclinical Males	-59.4/33.7	-60.6/-24.4	-12.7/-23.6	-10.6/-23.0	-62.4/-24.4	-61.8/-23.6
Standard Deviation	26.5/27.8	28.2/17.9	15.6/27.1	13.4/17.8	20.3/22.7	26.4/27.8

5.0 DISCUSSION

5.1 Summary of Major Findings

This thesis investigated biomechanical (muscle activity and kinematics), physiological (heart rate and breathing) and subjective discomfort differences across sex and NP populations during long duration smartphone and laptop use. To date, few studies have investigated long duration data collection for mobile device use and one goal of this thesis was to determine if shorter duration data collections could accurately extrapolate findings to longer duration or full day effects of mobile device use. The aim of this study was to determine if slumped/flexed head and neck postures for long durations would increase discomfort and would subclinical NP users experience higher discomfort levels, increased neck muscle activity and different cervical kinematics than healthy participants.

In general, the subclinical participants produced higher discomfort scores than the healthy participants during the smartphone and laptop tasks. The discomfort scores also, in general, increased as time progressed with both the smartphone and laptop tasks. These increases were not linear and displayed subjective variability that makes it difficult to extrapolate short duration data collection findings to full day evaluations. The subclinical NP participants had higher average muscle activity for all six muscles (cervical extensor, upper trapezius and anterior deltoid, bilaterally) than the healthy participants for the 10th, 50th and 90th percentile APDFs. This suggests that NP individuals had higher muscle activity throughout the duration of the data collection protocol than healthy individuals. Additionally, healthy males tended to spend more time with low level EMG (below our gap threshold) and had a greater number of gaps than females. This suggests that our healthy males were able to turn off or produce very low level muscle activity throughout the duration of the data collection protocol. Subclinical NP participants continuously had greater neck flexion than healthy participants across both smartphone and laptop tasks and this was evident for the 10th, 50th and 90th percentiles of the APDF

analysis. Interestingly, healthy females displayed a greater gaze angle than the subclinical females while subclinical males had greater gaze angles than the healthy males. Despite clear differences between groups for most of our measures, there were few significant differences. Therefore, descriptive results were presented to highlight these differences and this work suggests that individual strategies produces variability that could mean a greater number of participants may be needed in each group to provide conclusive evidence.

5.2 Discomfort

The laptop and smartphone tasks had similar discomfort scores reported across the same body segments. But in general, the subclinical NP participants reported higher discomfort scores than the healthy participants. Other studies have shown that neck flexion is reported to cause neck discomfort and upper limb disorders (Ohlsson et al. 1995; Hünig et al, 1980). Also, poor posture in the cervical spine and scapula during prolonged sitting has been linked to discomfort and pain within the muscles if held for long durations of time or with high frequency (Genaidy & Karwowski, 1993). This may explain when sitting with a flexed neck for long durations of time participants reported pain in their shoulders and arms despite no strenuous activity being done. A study by Powell, Kelly, & Williams (2001) found the minimum clinical significant difference in visual analog scales (VAS) (on a 100 mm VAS scale) to be 10 mm (95% confidence interval 7 to 12 mm). Although this thesis found few significant differences with the discomfort scores, the values presented in this thesis do increase to over 10 mm of discomfort.

5.3 Muscle Activity - APDF

The 10th percentile ADPF represents low level muscle activity, 50th percentile APDF represents average (median) muscle activity throughout our data collection and the 90th percentile APDF represents maximum muscle activity. Despite few significant differences being found for the smartphone and

laptop 10th, 50th and 90th percentile analyses, there were interesting differences that were noticed between sex and groups. In general, females tended to have greater muscle activity than males for the majority of the muscles monitored. One reason why females may have produced greater CE muscle activity for the 10th percentile APDF may be due to sex differences in muscular size of the neck, which can lead to differences in muscular endurance. A study by Vasavada et al., 2008 found female necks were significantly weaker than male necks (32% weaker in flexion and 20% weaker in extension; $p < 0.001$). This could cause females to develop muscular injuries as a result of long duration flexed head and neck postures when using mobile devices. This could also explain why we found it was more difficult to recruit subclinical NP male participants for this thesis study.

Interestingly, Xie et al. (2015) also did not find many significant differences across the muscles examined between their healthy and chronic NP participants. Xie et al., (2015) also compared the tasks of typing and texting and, not surprisingly, there were muscle activity differences found between the tasks. Similar to Xie and colleagues, this thesis did not observe many muscle activity differences between healthy and NP participants. However, given the findings of Xie and colleagues, it may be beneficial to evaluate our tasks within each condition.

5.3.1 Smartphone (50th percentile APDF)

There was one significant interaction found between sex and group ($p = 0.023$, $F_{1,14} = 6.552$) for the left CE. There is a clear distinction between females and healthy participants (Figure 9). Females had larger mean muscle activity for the left and right CE (left CE: $9.5 \pm 2.0\%$ MVE, right CE: $10.5 \pm 2.2\%$ MVE) when compared to males (left CE: $7.1 \pm 2.3\%$ MVE, right CE: $6.8 \pm 2.6\%$ MVE). Healthy participants also had greater muscle activity for the left and right CE (left CE: $25.6 \pm 2.0\%$ MVE, right CE: $9.0 \pm 2.2\%$ MVE) when compared to subclinical NP (left CE: $11.0 \pm 2.3\%$ MVE, right CE: $8.3 \pm 2.6\%$ MVE). These findings may explain the significant difference by illustrating subclinical NP

females produced greater muscle activity than the other groups and males. Xie et al. (2015) compared bilateral and unilateral typing on a smart phone and typing on a desktop computer with healthy and neck and shoulder pain participants. Xie et al. (2015) did not separate their findings into males and females, they only compared healthy (control) and NP participants (case) for each task. This study did not compare muscles bilaterally, rather the authors lumped all muscle APDF data together. For the cervical erector spinae muscles (not significant) 50th percentile analysis, the authors found the following: bilateral smart phone texting (NP: 13.32 ± 6.39 %MVE, healthy: 11.31 ± 4.18 %MVE), unilateral smart phone texting NP: 13.72 ± 6.13 %MVE, healthy, 11.84 ± 5.32 %MVE) and typing on a desktop computer (NP: 12.81 ± 5.46 %MVE, healthy: 9.86 ± 5.33 %MVE). This thesis found that healthy participants had greater muscle activity than the subclinical NP participants for the CE muscles. This finding is opposite to what Xie et al., (2015) demonstrated for their 50th percentile APDF data which was that the NP participants consistently had greater muscle activity than healthy participants. Due to methodological differences, direct comparison of the two studies can be difficult. Regardless, the differences between this thesis and Xie et al., (2015) could be due to data collection time differences and that this thesis had participants interact with their smart phones during other tasks, not just texting. The results of this thesis healthy participants having greater muscle activity than subclinical NP participants for the left CE could be explained by the healthy participants not resting their muscles as much as the NP participants and if this trend were to continue for long durations of time on a daily basis, this could result in musculoskeletal injuries. Perhaps the healthy participants are having to activate their muscles more than the NP participants since it is needed to hold the postures they were in. As a result, daily long duration high muscle activity in the healthy participants could result in these healthy participants becoming NP participants.

5.3.2 Smartphone (90th percentile APDF)

The 90th percentile APDF, represents maximum muscle activity. There was a significant main effect of group ($p=0.014$, $F_{1,14}=7.968$) for the left CE (Figure 10). Healthy participants had greater muscle activity for the left CE ($11.4 \pm 2.9\%$ MVE) when compared to the subclinical NP participants ($10.5 \pm 3.3\%$ MVE). This finding is also opposite to what Xie et al., (2015) found for their 50th percentile APDF data, which was the NP participants had greater activity. The 90th percentile cervical erector spinae values for Xie et al. (2015) were the following: bilateral smart phone texting (NP: $19.11 \pm 8.70\%$ MVE, healthy: $16.01 \pm 6.16\%$ MVE and unilateral smartphone texting (NP: $19.53 \pm 8.41\%$ MVE, healthy $16.84 \pm 7.14\%$ MVE). Interestingly, these 90th percentile values are greater than what was found in our study. These differences could be due to differences in time of data collection protocol and that this thesis also had participants doing other tasks on their smart phones.

5.3.3 Laptop (90th percentile APDF)

For the left UT, there was a significant main effect for sex ($P=0.050$, $F_{1,14}=4.579$), where females had a mean muscle activity of $16.4 \pm 4.3\%$ MVE while males had a mean of $2.3 \pm 4.9\%$ MVE. Healthy participants had a mean of $13.9 \pm 4.3\%$ MVE while subclinical NP participants had a mean of $5.4 \pm 4.9\%$ MVE. Xie et al. (2015) demonstrated left UT muscle activity of $6.5 \pm 2.9\%$ MVE for the 90th percentile, while our study found $13.9 \pm 4.3\%$ %MVE. In our study we found that subclinical NP participants had left UT muscle activity of $5.4 \pm 4.9\%$ MVC compared to $14.7 \pm 11.8\%$ MVE during the Xie study. These differences are surprising and could be a reflection of the methods, the conditions or the ergonomic set up of the experiments. In addition, perhaps this is a sign that our healthy participants are starting to develop subclinical NP muscle activity levels within their UT.

Repeated sub-maximal exertions, like those found in this thesis, performed over long periods of time can result in cumulative neck loading. This can link laptop computer and smartphone use to increased risk of upper extremity musculoskeletal disorders through a combination of poor head and neck postures and low level static exertions of the neck musculature (Chany et al., 2007). With both laptop computer and smartphone use, neck musculature has to stabilize the head and neck for visual purposes. Our 10th percentiles APDF values are a good representation of these low level sub-maximal exertions. Despite no significant differences being found within the cervical extensors during the smartphone or laptop tasks, the low level muscle activity can lead to cumulative loading which could contribute to injuries if continued for long durations of time. We found no significant differences between our groups (healthy and subclinical NP), however, CE muscle activity approaching approximately 10% MVE in our pain could be considered a high level of muscle activity that is statically held for long periods of time. Even low CE activity of 1-3% MVE should be considered as a potential injury mechanism during mobile device use.

5.4 Gaps Analysis

A gaps analysis was performed for both smartphone and laptop tasks to determine the time spent below a set muscle activity threshold (2% MVE) during the tasks. Gaps analysis represents the number of times and the amount of time a muscle spends in a “silent” or rest period.

5.4.1 Smartphone

There were significant differences found within the smartphone task for the number of gaps and average gap time. For the right CE, healthy males produced the least amount of gaps (0.30 ± 9.5) when compared to healthy females' (11.3 ± 9.5) and to the subclinical females' (1.5 ± 9.5). This is an important finding because it illustrates that healthy female participants had more gaps suggesting that they may rest and turn off important muscles more than the subclinical pain groups. There was also a

significant sex difference for the left AD during the smartphone task. Females had double the number of gaps (40.8 ± 17.1) than males (20.4 ± 19.7) illustrating the possibility of gender differences for ‘turning on and off’ muscles to rest. There was also a main effect of sex for the average gap time for the left UT. Males spent more time on average below the 2% threshold (118.0 ± 28.5 sec) (1.9 minutes out of the 30 minute trial) than females (17.9 ± 24.7 sec) (0.28 minutes).

A study by Blangsted et al. (2003) examined EMG gap time and gap frequency in female and male office workers. This study found that for the right UT the mean EMG gap time and the mean static EMG activity level was $1.1 \pm 1.3\%$ EMG_{max} during the total one hour work period for females. For males, the values during computer work was only $1.1 \pm 1.2\%$ EMG_{max} and during the total one hour period and $0.5 \pm 0.9\%$ EMG_{max}, respectively. The same patterns were seen for the left UT. There was no main effect of gender seen in the EMG gap time. Norander et al. (2000) found comparable results, no gender differences for EMG levels, the EMG gap time or the gap frequency of the UT among office workers performing normal work. Norander et al. (2000) and Åkesson et al. (1997) have shown that subjects with pain have a lower static load than healthy participants.

5.4.2 Laptop

The only significant difference found was the number of gaps for the right AD. Healthy participants had a greater number of times below the 2% threshold (124.6 ± 36.3) than subclinical participants (86.0 ± 41.9). This result indicates that the healthy participants’ right AD muscles were resting more often than the NP group. These results further illustrates that there are differences in muscle activation within upper extremity muscles during long duration mobile device tasks between healthy and subclinical NP participants.

5.5 Heart Rate

Heart rate remained stable throughout the laptop and smartphone tasks. This finding was opposite to what was expected according to previous work (MacWilliam, 1933, Van Lieshout et al., 2005 & Lim et al., 2011). Even if changes were found, it would have been difficult to determine if the change in heart rate was due to head and neck posture or if the change in heart rate was due to physiological stimulation associated with the tasks. Such as the study conducted by Lin and Peper, 2009 who investigated the psychophysiological patterns associated with smartphone text messaging in college students. The authors found an increase in heart rate which they concluded was due to psychological factors of excitement and anticipation when texting and not associating with head or upper body posture.

5.6 Kinematics

In general the subclinical NP participants had greater average and peak neck flexion than healthy participants. Males also had larger neck flexion angles than females. Similar findings have been reported previously in young adults (Guan et al., 2016). A potential reason for these poor working postures and increased discomfort is the connected keyboard and monitor in laptop designs which allows them to be portable. This reduces the ability to adjust the computer monitor separately from the keyboard unlike desktop computers. In previous work, it was found that the mean neck posture when using laptop computers was 4° of flexion (Werth & Reeves, 2014). The findings of this thesis are similar to Werth & Reeves' study in 2014 (1.5° during the 10th percentile, 5.7° during the 50th percentile and 10.0° during the 90th percentile). Laptop head flexion angles could contribute to the development of musculoskeletal disorders if these adapted postures are maintained for long durations of time (Ariëns, et al., 2001; Sommerich, et al., 2001 & Straker, et al., 2009). This is important because average APDF head flexion angles were greater for the smartphone tasks than the laptop tasks within our study.

Gustafsson, 2012 found that individuals who interacted with their mobile devices and sat with their head in a flexed position more commonly experienced musculoskeletal injury symptoms. Sitting with the head bent forward was more common in the group with musculoskeletal symptoms compared with the group without symptoms (Gustafsson et al., 2011). In our work, subclinical NP participants had greater head and neck flexion angles than healthy participants. Healthy participants had head flexion angles of: 5.8° , 10.8° , 15.8° for the 10th, 50th and 90th, respectively. These head flexion angles of healthy participants are lower than the head flexion angles of the subclinical NP participants within this thesis of: 14.0° , 17.9° , 21.4° for the 10th, 50th and 90th, respectively. Two prospective cohort studies both found an increased risk for neck or neck and shoulder pain or sick leave due to NP during work with neck flexion greater than 20° for more than 40% of the working time and greater than 45° for more than 5% of working time (Ariens et al., 2002 & Andersen et al., 2003). However, the head and neck flexion angles measured during our smartphone condition were not too much greater (maximum was 21.4° head flexion angle in this thesis) than 20° and none were held for 40% of the time. The 90th percentile APDF was the only percentile to have a neck flexion angle greater than 20° (for subclinical NP only), but this represents data that occurred for approximately 10% of the total task time.

Lee et al., 2014 concluded that participants maintained head flexion of 33° to 45° from vertical when using a smartphone (Lee et al., 2014). Similar to the computer users in the previous studies, Lee et al., 2014 concluded that smartphone users produced greater head flexion angles (33.3° to 44.8° in the 50th percentile). The head flexion angles in the Lee et al., 2014 study is comparable to the head flexion angles produced when using tablet computers on the lap or table in a sitting position, which ranges from 15° to 25° of head flexion (Young, et al., 2012). The large flexion angles that were seen in these two studies were not seen within our study. This is probably because when the participants in Lee et al.'s, 2014 study were sitting, there was no table that the participants could rest their arms on. The participants

most likely rested their elbows against themselves as they got tired which created the larger head and neck flexion angles when using a smartphone. Young et al., 2012 reported head flexion ranges that were closer to the results of our study but was still greater overall.

5.7 Gaze Angles

A study by Straker et al., 2009 used a musculoskeletal neck model to conclude that gaze angles below -45° can increase strain on the neck extensors. For our work, the smartphone tasks had more gaze angles greater than -45° than did the laptop tasks. This was expected since smartphones are smaller and easily manipulated more than a laptop screen, which can only be manipulated in two directions. There were also more gaze angles that were -45° and above within the subclinical NP participants. This shows that the NP participants were either being more cautious or perhaps had limited range of motion due to their NP. A study by Young et al., 2012 calculated gaze angles with two different tablet computer sizes and various tablet computer positions such as: resting on the participants lap while stabilizing the tablet with one hand and using the other hand to interact with the screen (lap-hand: -50°), using the tablet case on the lap without holding the tablet on their lap (lap-case: -51°), using the tablet case but resting it on a table in front of the participants (table-case: -46°) and watching a movie on the tablet in a case on a table in front of them (table-movie: -27°). Although this thesis only observed smartphone and laptop computer use and no attachable keyboard was used in Young et al., 2012, the table-case condition was the most similar to the smartphone set up in our study. All participants were seated in a chair and had a table in front of them. The subclinical NP gaze angles calculated for the smartphone condition for this thesis (table 4 in the results) were the closest to the -46° gaze angle found within the study by Young et al., 2012. Although the subclinical NP males smartphone gaze angles were in general higher (in the -60° gaze angle range) than the -46° gaze angle found within the study by Young et al., 2012. Another study by Saito et al., 1997 compared the viewing angle of a notebook computer (laptop) to a desktop computer and found the notebook computer produces lower average gaze angles (-35.0°) when compared to a

desktop computer (0.3°). This thesis did not look at desktop computers, but laptop computer interaction was observed and the viewing angle of the laptop within the study by Saito et al., 1997 is comparable to some the gaze angles of the laptop computer found within this thesis which can be found within table 4 in the results section. The majority of the laptop gaze angles found within this study are close or lower than the -35° viewing angle finding within the Saito et al., 1997 study occur within the subclinical NP participants. The laptop gaze angles were not as large as the smartphone gaze angles because laptop computer screens are not as maneuverable as smartphones.

5.8 Limitations

Like most research studies, there are some limitations to our work. Despite each participant having standard skin preparation for electrode placement, there were external noise inherent in some of our signals. However, we tried to minimize this by securing the sensors using Hypafix and double sided tape. As a result, some of the SEMG data had to be excluded. The data was carefully examined and if over 100% MVE, it was excluded since this data either contained external noise or the MVCs were not completed to the participant's full maximal extent. Another limitation to the study could be the extent of the instrumentation on each participant which could have contributed to the discomfort scores obtained. Each participant was instructed to ignore all of the sensors and use their device as they normally would. Given that this study was performed in a Neuromechanics Laboratory, it is also possible that each participant sat more upright and tried to use their device in a more ergonomically optimized posture, regardless of the investigators instructing them to move as they normally would. Finally, each group in this study has a small numbers of participants. The small sample size within each group, likely contributes to the significant findings, despite our best efforts to recruit NP participants it was at times difficult. It is likely that a larger sample size will yield more conclusive evidence towards potential differences in how pain and healthy users interact with their mobile devices.

6.0 CONCLUSION

The first aim of this study was to determine if slumped/flexed head and neck postures for long durations will increase discomfort and if subclinical NP users experience higher discomfort levels. This was confirmed within this thesis, in general the subclinical NP participants reported higher discomfort scores than the healthy participants. The second aim of this study was to determine if subclinical NP participants would produce higher muscle activity. Surprisingly, this was not always evident across all muscles monitored. In general, healthy participants produced greater muscle activity when compared to subclinical NP participants. Females also reported greater muscle activity than males, which suggests that future studies may need to specifically look into gender differences during mobile device use. The gender differences were also evident in the gaps analysis, with significant differences found for females having more gaps for the left CE and AD than males during the smartphone task. During the laptop task, it was found that the healthy participants had more gaps than the subclinical NP participants (for the right AD). The last aim of this thesis was to determine if subclinical NP participants produce different postures when interacting for long durations of time with their mobile devices. This was confirmed within this thesis. In general, the subclinical NP participants had greater average and peak neck flexion than healthy participants. Interestingly, the healthy males produced head and neck flexion angles that were within the ranges of the subclinical NP males and females for both the laptop and smartphone tasks. While the healthy females for both conditions had relatively neutral head and neck angles in comparison. Perhaps the neck pain participants were not experiencing pain during both days of data collection. Or more interestingly, perhaps the healthy males producing kinematics like the NP participants is a biomarker of the healthy males developing NP shortly. Subclinical NP participants also produced more gaze angles that were -45° (end limit of what is considered safe based on ergonomic guidelines) and above. This work is important because it evaluated long duration smartphone and laptop

computer usage, which has seen limited attention in the literature to date. Further investigation should attempt to determine if the differences found between groups can help identify or pre-determine if an individual may be predisposed to NP or injury due to increased device use.

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CHAPTER 4: APPENDICES

Appendix A1

Victoria Breitner
University of Ontario Institute of Technology
Graduate Student, Health Sciences, Kinesiology
2000 Simcoe St. North
Oshawa, Ontario
CANADA L1H 7K4
Email: victoria.breitner@uoit.net

Letter of information and consent form

Title of Project: Biomechanical and Physiological Demands associated with Laptop and Mobile Phone Use in a Subclinical Neck Pain and Healthy University Aged Population

You are invited to participate in a research study entitled “Biomechanical and Physiological Demands associated with Laptop and Mobile Phone Use in a Subclinical Neck Pain and Healthy University Aged Population”. This study (REB # 14-109) has been received by the UOIT Research Ethics Board and has been approved as of (Date: Friday, Aug. 28, 2015). Please read this form carefully, and feel free to ask any questions. If you have any questions about your rights as a participant in this study, please contact the Compliance Officer at 905-721-8668 ext 3693 or compliance@uoit.ca

Researchers

Michael Holmes, Faculty of Health Sciences. Email: michael.holmes@uoit.net

Victoria Breitner, Graduate Student in Health Sciences (Kinesiology). Email: victoria.breitner@uoit.net

Purpose of the Study

There are five parts to the purpose of this research.

- 1) To determine muscle activation and recruitment patterns (bilaterally) for the upper trapezius, cervical extensor, and anterior deltoid during long duration mobile computing.
- 2) To determine the magnitude of forces on the cervical spine during mobile computing.
- 3) To determine if individuals with subclinical neck pain produce different kinematics and muscle activity patterns than healthy individuals when using laptop and mobile phone devices for extended periods of time?

- 4) To determine what impact long term laptop and mobile phone use has on resting heart rate and breathing efficiency.
- 5) To determine user discomfort scores with prolonged laptop and mobile phone use.

Potential Benefits to Participant and/or to Society

There are no known or anticipated direct benefits to the participants from their involvement in this project.

It is anticipated that the results of this work will create new knowledge of the possible physiological side effects and possible ranges of cervical motion that will promote musculoskeletal injuries when using laptops and mobile phones. This study could also lead to possible mobile device modification.

Participation and Withdrawal

Your participation in this study is voluntary. You may withdraw from this study at any time without consequence. To do so, indicate to the researcher by saying, “I no longer wish to participate in this study”. If you wish to withdrawal from this study your data will be permanently discarded and all paper copies (consent form, surveys, etc.) will be destroyed.

If you wish to withdraw consent after the study has ended, please contact the researchers and they will remove you from the study.

The data may be used in future studies.

Rights of Research Participants

To assure ongoing consent, at various transition points in the experiment all participants will be reminded of the voluntary nature of continuing further, and that all the protections of the original consent letter are still in force.

You are free to ask any questions about your rights as a research participant. You may withdraw your consent at any time and discontinue participation without consequence. If any questions come up during or after the study, contact the study researchers listed on the first page.

Eligibility

Male or female participants (age range 18-40 years) are being recruited. We are seeking individuals who: 1) have not had chronic spine or upper extremity pain in the past 12 months, 2) individuals who have had subclinical neck pain (pain in the neck and upper extremity but have not sought medical attention in the past 6 months), and 3) use a laptop and a mobile phone on a daily basis.

Procedures Involved in this Study and Time Commitment

Description

Background Rationale: Technology is advancing and is being incorporated more into the daily lives of many individuals globally. The quick advances in technology and increased popularity has not always allowed for ergonomic assessments and interventions to be used on some technological devices which can result in poor posture and musculoskeletal injuries [1]. Human-computer interaction has had extensive ergonomic research and workstation guidelines have been developed [1]. However, computers can still promote forward flexed neck postures when the individual becomes fatigued and uncomfortable from sitting, especially with laptop computers [2]. Many occupations have some form of computer work and sometimes the same individuals continue to use computers at home. Due to the novelty of mobile phones, they have not seen the same ergonomic focus [3]. It is understood that individuals are not constantly using their mobile phones, but statistics illustrate an increase usage globally [4]. Therefore, the frequency and duration of mobile phone use are important factors to consider when identifying adapted cervical posture changes. Technology is also used more frequently by teenagers and youths than in the past. [5, 6, 7 & 8].

Any year 3 or above UOIT student can participate in this study since previous articles indicate no significant associations between gender, neck posture, and musculoskeletal injuries [3]. Year 3 or above UOIT students are the target population due to their amount of laptop computer usage.

It is assumed there will be an increase in the heart rate and a decrease in pulmonary function due to various research articles which have linked altered upper body postures to increased resting heart rate, changes in the ribcage and the upper airway shape which decreased ventilation [9 & 10]. This work attempts to fill a knowledge gap by linking the adopted forward flexed postures when using these technologies to potential changes in heart rate and ventilation. This study will also determine the amount of force (i.e. the weight of the head, gravitational pull, torque, and shear) produced when the cervical spine is flexed. Another study by Hansraj in 2015 determined some of these values but the article could be improved by the use of surface electromyography and a motion capture camera system which will allow for more accurate cervical spine angles (i.e. flexion, extension, rotation, and medial lateral deviation) to be determined and the resulting forces to be calculated.

Many of the articles investigating computer and mobile phone use in sitting postures have used short task durations with breaks between activities [2]. However, most computer interaction is not short duration. Therefore this study will investigate both laptop and mobile phone use for a longer duration (2 hours). This will allow for an association between posture, heart rate, breathing and musculoskeletal symptoms within subclinical neck pain and healthy individuals to be determined.

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Protocol: This study will compare muscle activity, cervical posture, breathing, heart rate and discomfort scores between a subclinical neck pain group and a healthy control group when using a laptop and a mobile phone in a student aged population. You will use your laptop, placed on a desk and while sitting in a chair for a duration of two hours and on a separate day, you will use your mobile phone for a duration of half an hour. Rest will be given between laptop computer and mobile phone trials to mitigate the effects of fatigue.

The only instruction given during the laptop computer protocol is to not watch any videos. You are free to browse the internet or work on word processing documents.

The mobile phone protocol will be divided into three predetermined randomized tasks. Ten minutes will be devoted to text messaging. Another ten minutes will be devoted to playing one game. Another ten minutes will be devoted to navigating around the Internet without watching video. The investigator will indicate when and what task to switch to.

The study aims to analyze laptop computer and mobile phone interaction which is why watching a video is prohibited for the purposes of this study.

Upon full completion of this study (completion of the questionnaires, laptop computer use, and mobile phone use) subjects will be given a \$10.00 Tim Hortons gift card. Should only a portion of the experiment be completed, a lesser value card (\$5.00) will be awarded.

Metrics/Instrumentation: After arrival to the lab and the initial questionnaires are complete, custom-molded rigid bodies consisting of infrared light emitting markers will be affixed to you such that three-dimensional positions and orientation of your body segments can be accurately measured with three optoelectronic cameras. Static posture will be recorded in the anatomical position (standing with arm at the sides and palms of the hands facing in front of you). Next, maximal active range of motion will be recorded with the optoelectronic cameras prior to testing.

Individual strobing markers will also be placed on the four corners of the laptop screen and on the mobile phone with tape to track the angle of the screen in relation to each subjects' cervical posture. Active maximal neck range of motion (flexion, extension, left and right rotation, and left and right lateral bending) will be measured in both subclinical neck pain and health subjects using the optoelectronic camera system.

Muscle activity will be recorded using surface electromyography (SEMG) and heart rate and breathing kinematics will be recorded using an electrocardiogram (EKG). Prior to electrode placement, standard skin preparations including shaving the surface and cleansing the skin with alcohol will be performed. SEMG will be recorded from five cervical and upper body muscle groups (bilaterally) with custom double-sided adhesives. Selected muscle groups will be the upper trapezius, cervical extensor, and anterior deltoid. An EKG sensor will be placed on the left anterior chest (4th rib and floating ribs) which will collect heart rate and detect changes in chest movement as you breathe. Following preparation, a 10 second resting trial to collect resting muscle activity, heart rate and breathing will be completed. After the resting trial you will perform a series of maximal voluntary contractions which will be used to normalize the EMG signals during analysis.

With both laptop computer and mobile phone protocols, a Discomfort Scale will be used during data collection every 5 minutes for the cell phone task and every 10 minutes for the laptop task. The Discomfort Scale will be administered using Likert scales on a tablet computer.

Timeline

Including instrumentation and experimental setup, it is estimated that you will be in the Neuromechanics laboratory for 2.5-3 hours. On a separate date, you will return to the Neuromechanics laboratory to complete the second half of the experiment. Including instrumentation and experimental setup for the mobile phone protocol, it is estimated that you will be in the Neuromechanics laboratory for 1-1.5 hours.

Risks and Discomforts

There may be minimal risk associated with this study. For instance, the use of electromyography may require tape to secure the electrodes to the skin. However, in the unlikely event there is irritation caused by the surface electrodes, this will fade in 1-2 days. As a requirement for electromyography investigations, maximal voluntary exertions are required. You may experience some mild muscle soreness as a result of these maximal contractions. However, these maximal activities can be considered similar to activities of daily living often experienced at home.

The use of the subjects' laptop and mobile phone will be exactly the same as those the subjects use in daily life. You may experience discomfort to the neck, shoulder or back muscles due to the duration of device use and posture. In the very unlikely event of injury, we do not have funds to cover treatment costs. We remind you that as a student, the student health insurance plan does cover chiropractic and physiotherapy care.

Compensation for Participation

Upon full completion of this study (completion of the questionnaires, laptop computer use, and mobile phone use) subjects will be given a \$10.00 Tim Hortons gift card. Should only a portion of the experiment be completed, a lesser value card (\$5.00) will be awarded.

Disclosure

Your identity will be kept confidential and only made available to the researcher. You will be identified only by a subject identification code during the data collection phase of the study. Only the researchers will have access to the actual identities of the participants, even during release of the study findings. All data will be stored in a secure area (UAB 355) locked in the supervisor's filing cabinet or on a secured computer server.

Please read the following before signing the consent form and remember to keep a copy for your own records.

By signing this form, I agree that:

- 1) The study has been explained to me. All my questions were answered to my satisfaction.
- 2) The possible harms and discomforts and the possible benefits (if any) of this study have been explained to me.
- 3) I know about the alternatives to taking part in this study. I understand that I have the right not to participate and the right to stop at any time.
- 4) The data collected in this study will be kept in a locked filing cabinet, and/or stored on a password protected computer at UOIT, Oshawa, Ontario.
- 5) I am aware that this study and my data may be used in future studies.
- 6) I hereby consent to participate.

I, agree to take part in this research.

Subject's Signature: Date:

- I have read and I understand the information for volunteers taking part in the study "Biomechanical and Physiological Demands associated with Laptop and Mobile Phone Use in a Subclinical Neck Pain and Healthy University Aged Population". I have had the opportunity to discuss this study. I am satisfied with the answers I have been given.

If you wish to receive a feedback letter about the results of this study, please sign below. If not, leave the signature section below blank.

Subject's Signature: Date:

Thank you very much for your time and help in making this study possible. If you have any questions or wish to know more please contact Victoria Breitner, a Graduate student of Health Sciences Kinesiology stream at the University of Ontario Institute of Technology, 2000 Simcoe St. North, Oshawa, Ontario, L1H 7K4, email: victoria.breitner@uoit.net

For any other queries regarding this study, please contact the UOIT Research and Ethics Committee Compliance officer (compliance@uoit.ca and 905-721-8668 ext. 3693).

I, the undersigned, have fully explained the relevant details of this research study to the participant named above and believe the participant has understood and has knowingly given their consent.

Printed Name

Date

Signature

Role in the Study (only authorized/qualified member of the research team)

Signing this form gives us your consent to be in this study. It tells us that you understand the information about the research study. When you sign this form, you do not give up your legal rights. Researchers or agencies involved in this research study still have their legal and professional responsibilities.

Appendix B1

Frequency and Usage of Mobile Device Questionnaire

Developed in part by the researchers and Korpinen, et al., 2009

Birthdate:

Weight:

Height:

1) How familiar are you with the following technological devices and services?

<i>Mobile phone and the associated services</i>	cannot say	very poorly	pretty poorly	moderately	pretty well	very well
<i>Portable computer</i>	cannot say	very poorly	pretty poorly	moderately	pretty well	very well
<i>Internet</i>	cannot say	very poorly	pretty poorly	moderately	pretty well	very well
<i>Electronic commerce</i>	cannot say	very poorly	pretty poorly	moderately	pretty well	very well
<i>Desktop computer</i>	cannot say	very poorly	pretty poorly	moderately	pretty well	very well

2) How often do you use the following for leisure activities?

<i>Mobile phone and the associated services</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Portable computer</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Internet</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Electronic commerce</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Desktop computer</i>	cannot say	not at all	less than monthly	monthly	weekly	daily

3) How often do you use the following for school activities?

<i>Mobile phone and the associated services</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Portable computer</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Internet</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Electronic commerce</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Desktop computer</i>	cannot say	not at all	less than monthly	monthly	weekly	daily

4) How often do you use the following for work activities?

<i>Mobile phone and the associated services</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
---	------------	------------	-------------------	---------	--------	-------

<i>Portable computer</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Internet</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Electronic commerce</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Desktop computer</i>	cannot say	not at all	less than monthly	monthly	weekly	daily
<i>Not working at this time</i>						

5) How important are the following for your leisure activities?

<i>Mobile phone and the associated services</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Portable computer</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Internet</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Electronic commerce</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Desktop computer</i>	cannot say	not at all	little	moderately	quite important	very important

6) How important are the following for you school activities?

<i>Mobile phone and the associated services</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Portable computer</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Internet</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Electronic commerce</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Desktop computer</i>	cannot say	not at all	little	moderately	quite important	very important

7) How important are the following for your work activities?

<i>Mobile phone and the associated services</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Portable computer</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Internet</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Electronic commerce</i>	cannot say	not at all	little	moderately	quite important	very important
<i>Desktop computer</i>	cannot say	not at all	little	moderately	quite important	very important

Not working at this time

8) When using your mobile phone do you:

<i>Send or receive email</i>	Yes	No
<i>Download software application or “app”</i>	Yes	No
<i>Access the Internet</i>	Yes	No
<i>Participate in video calls or video chat</i>	Yes	No
<i>Listen to music</i>	Yes	No
<i>Send or receive text messages</i>	Yes	No
<i>Watch videos</i>	Yes	No
<i>Play games</i>	Yes	No
<i>Get directions</i>	Yes	No

9) When using your laptop do you:

<i>Send or receive email</i>	Yes	No
<i>Access the Internet</i>	Yes	No
<i>Participate in video calls or video chat</i>	Yes	No
<i>Listen to music</i>	Yes	No
<i>Watch videos</i>	Yes	No
<i>Play games</i>	Yes	No
<i>Get directions</i>	Yes	No

10) Have you had an ache, pain or numbness which you associated with the portable computer use in the following body segments during the last 12 months?

<i>Wrist and fingers</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Elbows and forearms</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Neck</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Shoulders</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Lower back</i>	cannot say	not at all	sometimes	pretty often	often	very often

11) Have you had an ache, pain or numbness which you associated with a desktop computer use in the following body segments during the last 12 months?

<i>Wrist and fingers</i>	cannot say	not at all	sometimes	pretty often	often	very often
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<i>Elbows and forearms</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Neck</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Shoulders</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Lower back</i>	cannot say	not at all	sometimes	pretty often	often	very often

12) Have you had an ache, pain or numbness which you associated with mobile phone use in the following body segments during the last 12 months?

<i>Wrist and fingers</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Elbows and forearms</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Neck</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Shoulders</i>	cannot say	not at all	sometimes	pretty often	often	very often
<i>Lower back</i>	cannot say	not at all	sometimes	pretty often	often	very often

13) Why type of laptop do you use most frequently? Please print on the line below (i.e. UOIT's Lenovo ThinkPad; Model: T440p).

14) What type of mobile phone do you use most frequently? Please print on the line below.

15) In a week, estimate the cumulated time you use your mobile phone.

16) At any given time, what is the longest amount of time you are using your phone?

17) At any given time, what is the longest amount of time you are using your laptop?

18) On average, how frequently do you use your mobile phone in a day?

0 times
1-2 times,

2-3 times,
3-4 times,
5-6 times,
7-8 times
9-10 times
>10 times

19) On average, how frequently do you use your laptop in a day?

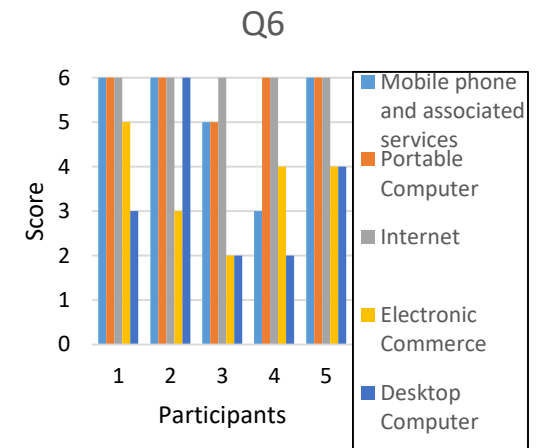
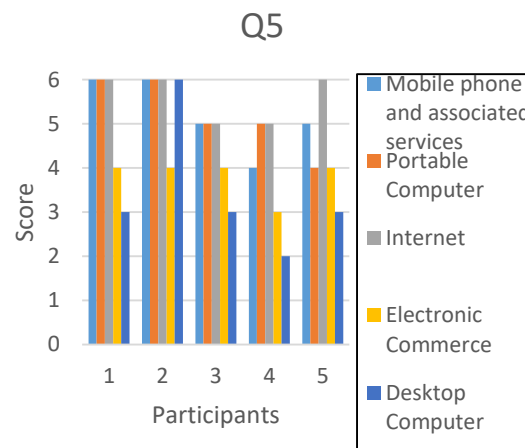
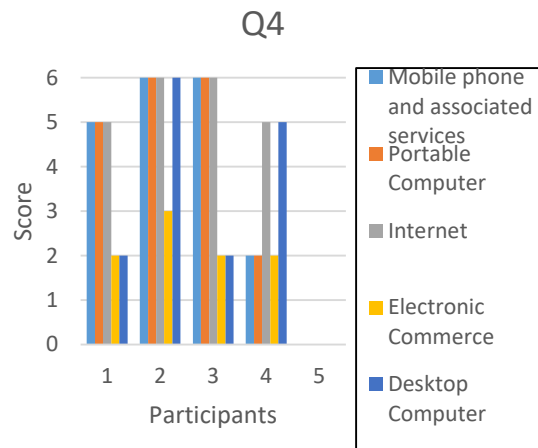
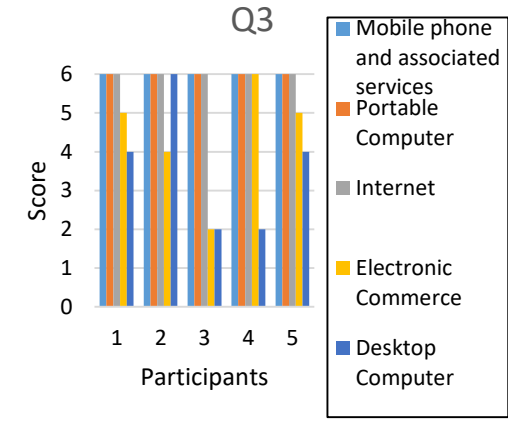
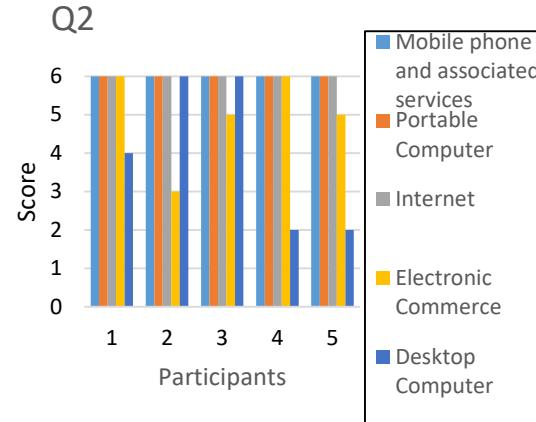
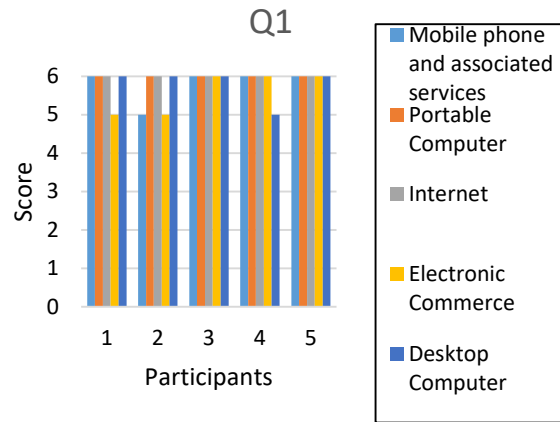
1-2 times,
3-4 times,
5-6 times,
7-8 times,
9-10 times,
>10 times

20) Are there are days of the week you **do not** use your mobile phone? (Circle all that apply).

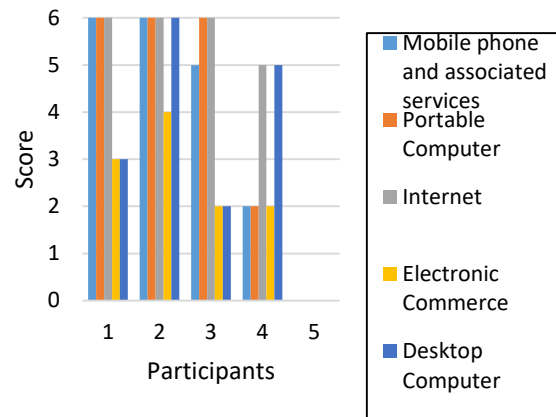
Sunday Monday Tuesday Wednesday Thursday Friday Saturday

21) Are there are days of the week you **do not** use your laptop computer? (Circle all that apply).

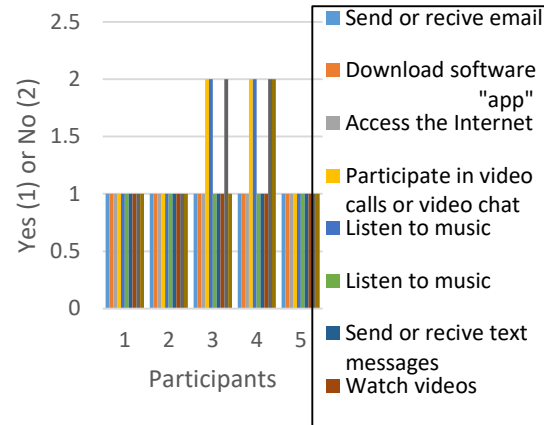
Sunday Monday Tuesday Wednesday Thursday Friday Saturday

Appendix B2: Results of Questionnaire Laptop and Mobile Phone Use

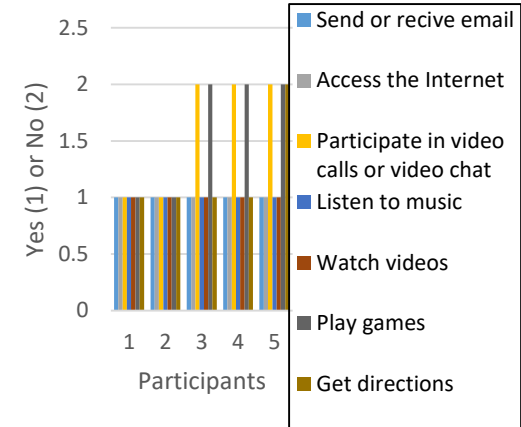
Q7



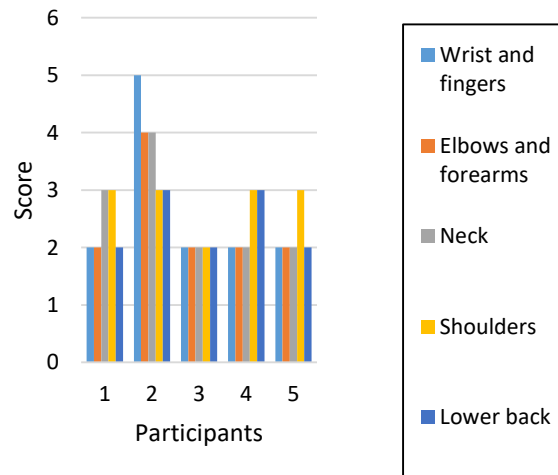
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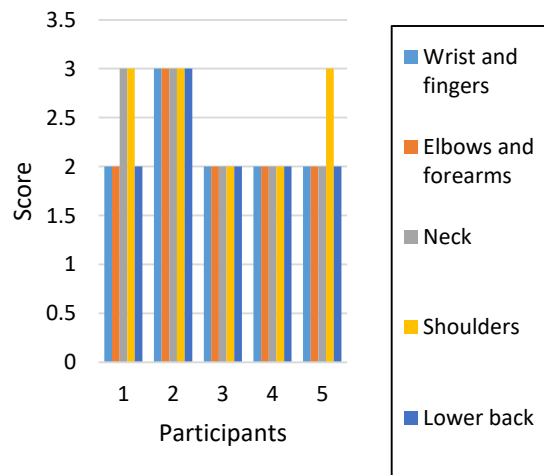
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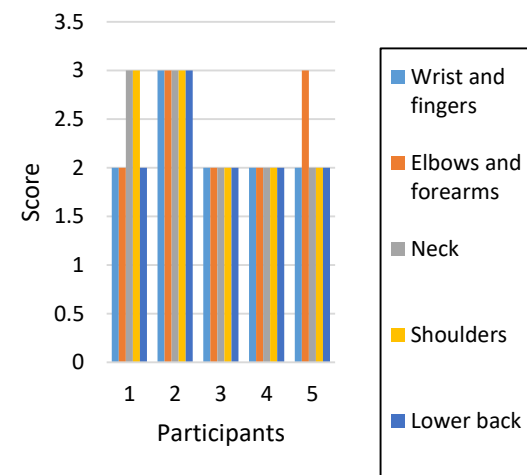
Q10

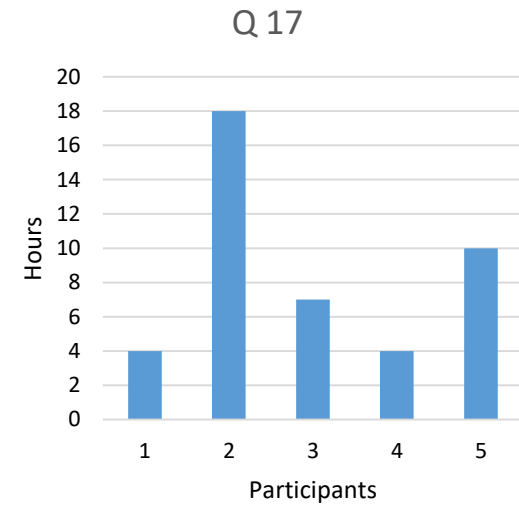
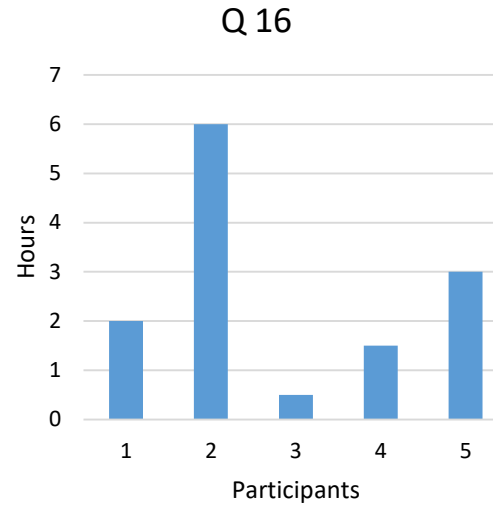
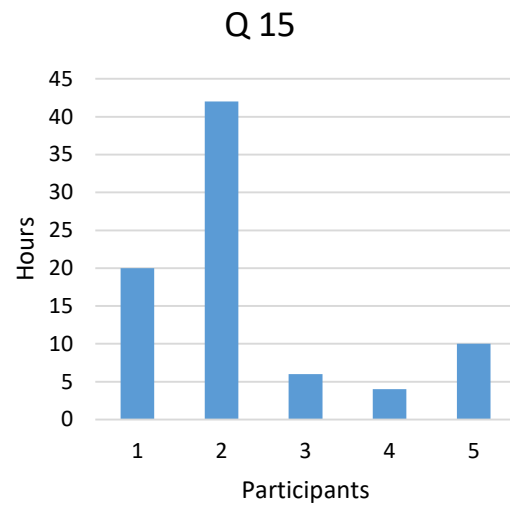


Q11



Q12





All graphs above correspond to the five healthy female responses to the questionnaire in Appendix B1.

Table 1: Healthy female responses to question 18.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
0 times					
1-2 times					
2-3 times					
3-4 times					
4-5 times					
5-6 times					
6-7 times					
7-8 times					
8-9 times					Yes
≥10 Times	Yes	Yes	Yes	Yes	

Table 2: Healthy female responses to question 19.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
0 times					
1-2 times					
2-3 times					
3-4 times			Yes		
4-5 times					
5-6 times				Yes	Yes
6-7 times					
7-8 times					
8-9 times					
≥10 Times	Yes	Yes			

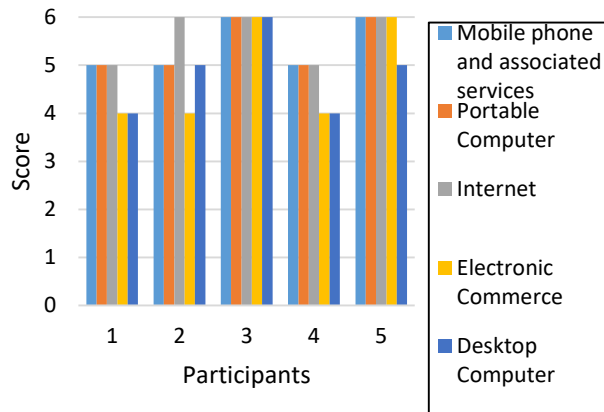
Table 3: Healthy female responses to question 20.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Saturday					
Sunday					
Monday					
Tuesday					
Wednesday					
Thursday					
Friday					

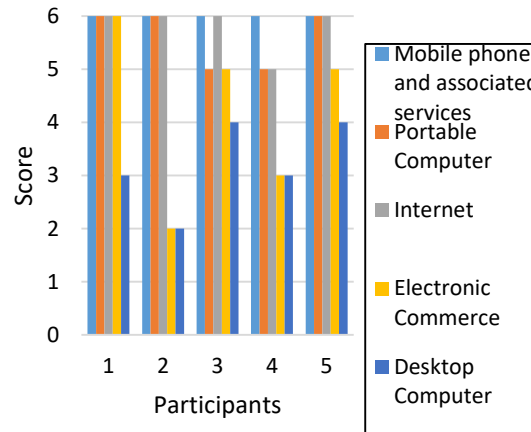
Table 4: Healthy female responses to question 21.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Saturday					Yes
Sunday			Yes		
Monday					
Tuesday					
Wednesday				Yes	
Thursday					
Friday					

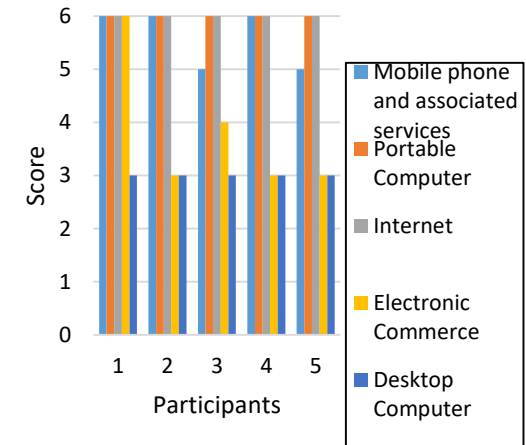
Q 1



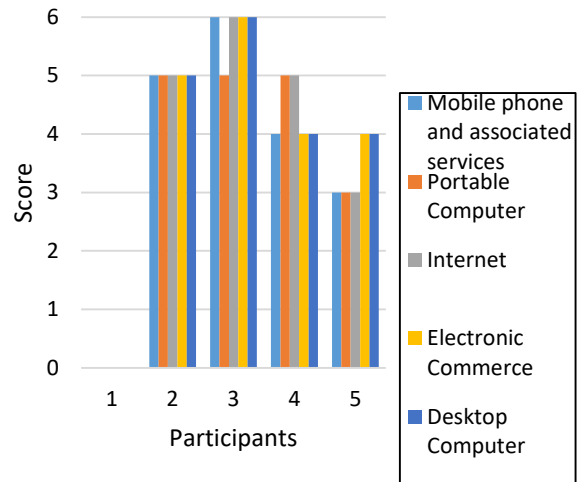
Q 2



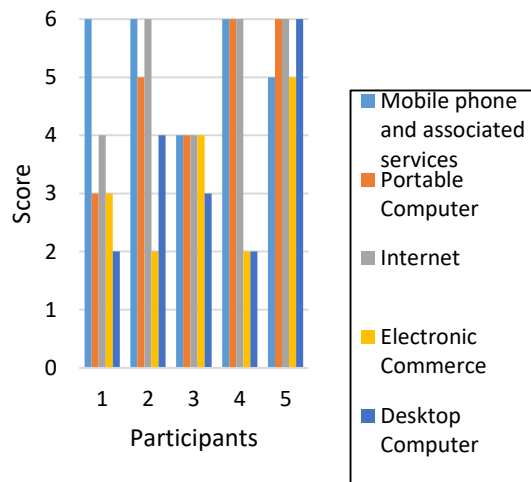
Q 3



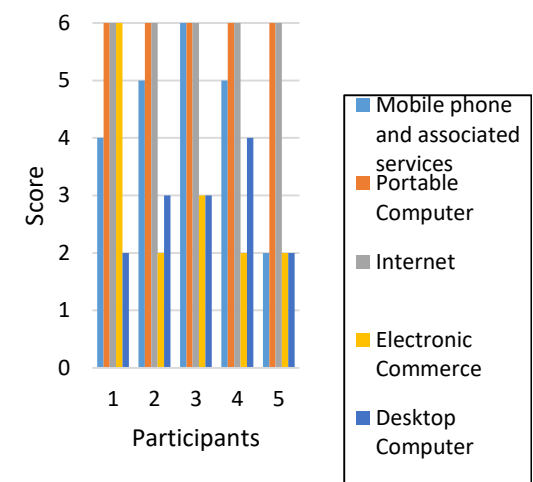
Q 4

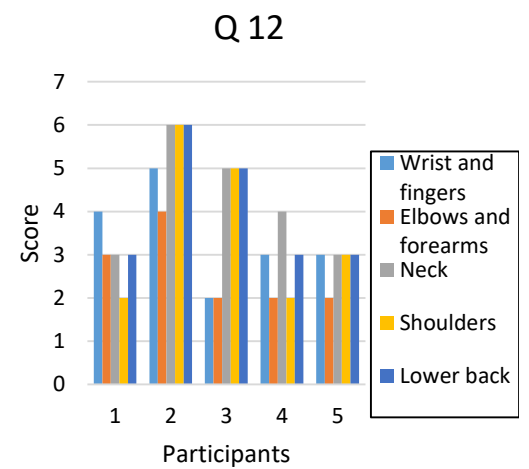
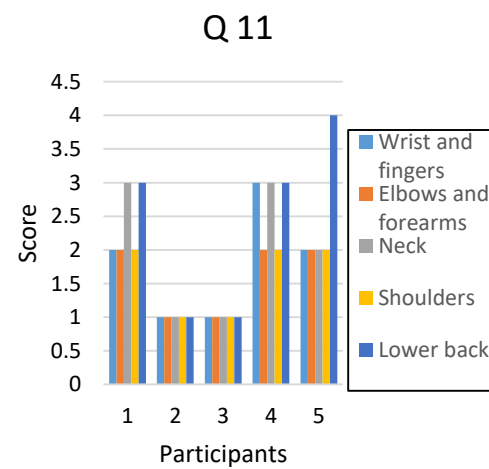
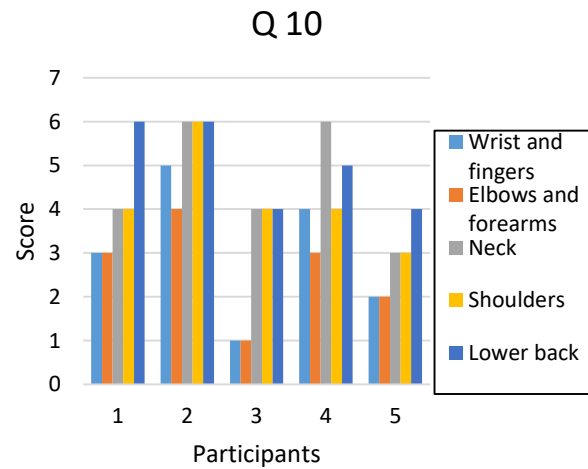
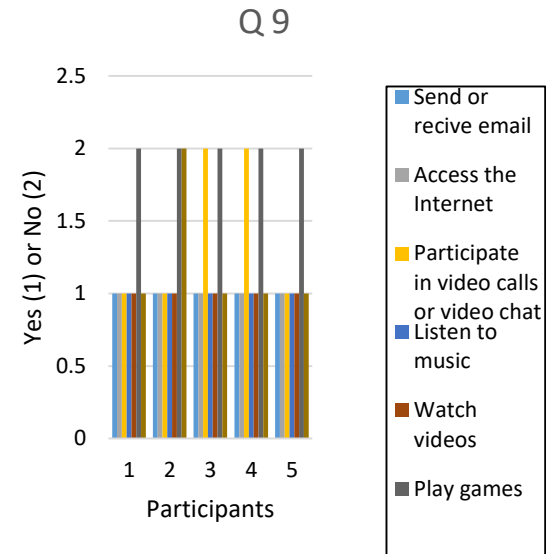
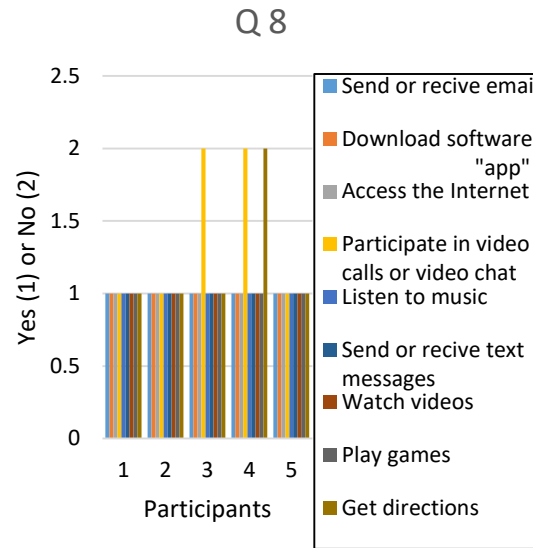
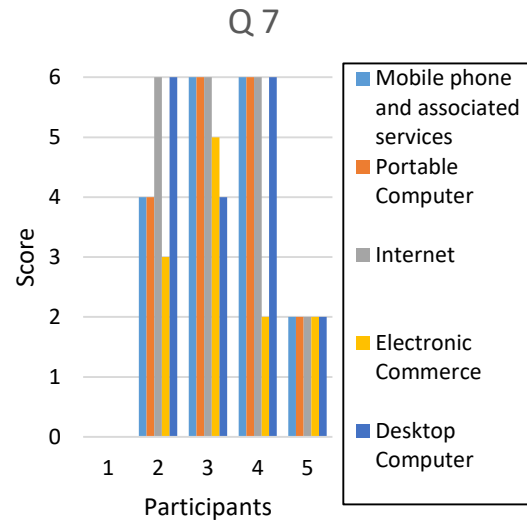


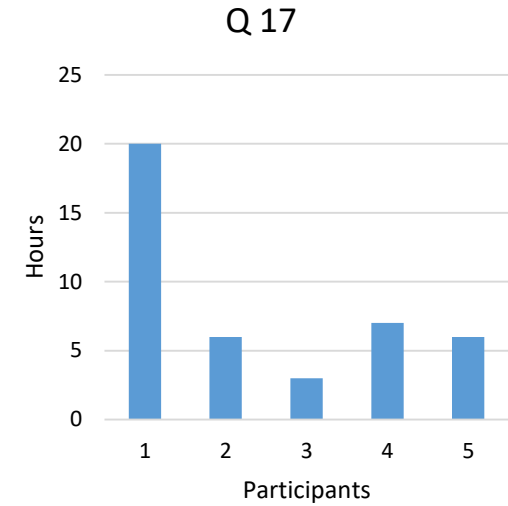
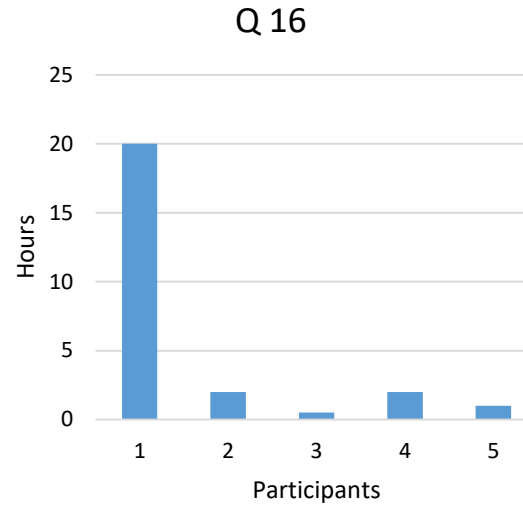
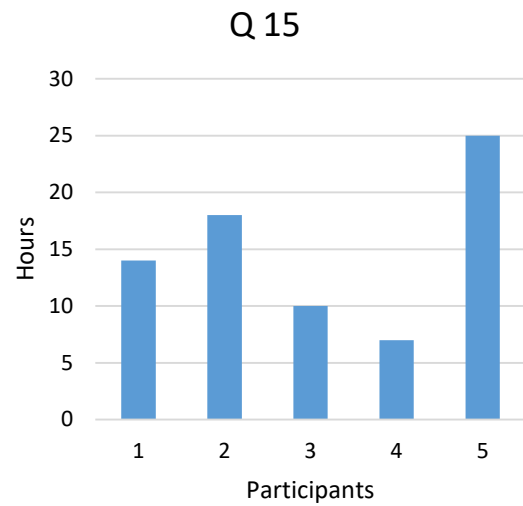
Q 5



Q 6







All graphs above correspond to the five subclinical NP female responses to the questionnaire in Appendix B1.

Table 5: NP female responses to question 18.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
0 times					
1-2 times					
2-3 times					
3-4 times					
4-5 times					
5-6 times		Yes			
6-7 times					
7-8 times					
8-9 times					
≥10 Times	Yes		Yes	Yes	Yes

Table 6: NP female responses to question 19.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
0 times					
1-2 times					
2-3 times					
3-4 times			Yes		Yes
4-5 times					
5-6 times				Yes	
6-7 times					
7-8 times					
8-9 times					
≥10 Times	Yes	Yes			

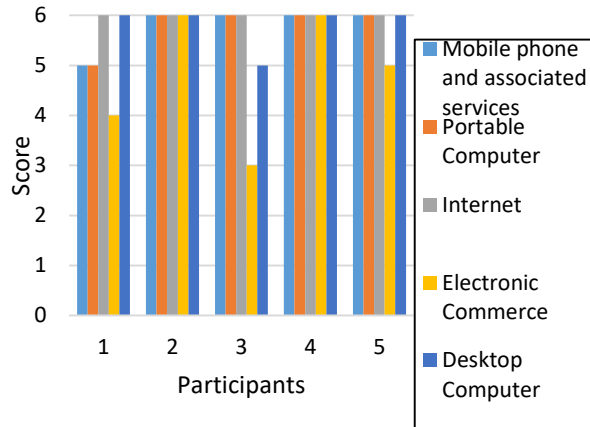
Table 7: NP female responses to question 20.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Saturday					
Sunday		Yes			
Monday					
Tuesday					
Wednesday					
Thursday					
Friday					

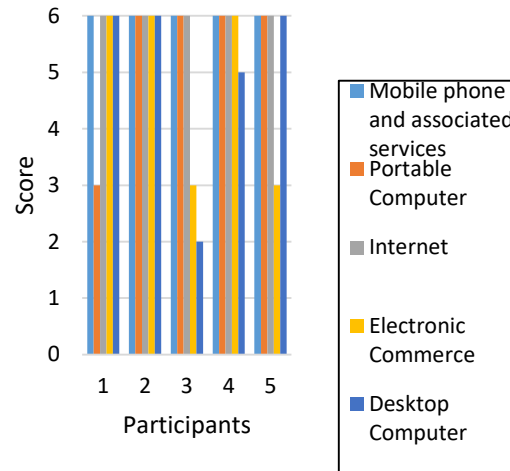
Table 8: Healthy female responses to question 21.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Saturday				Yes	Yes
Sunday					
Monday					
Tuesday					
Wednesday					
Thursday					
Friday					

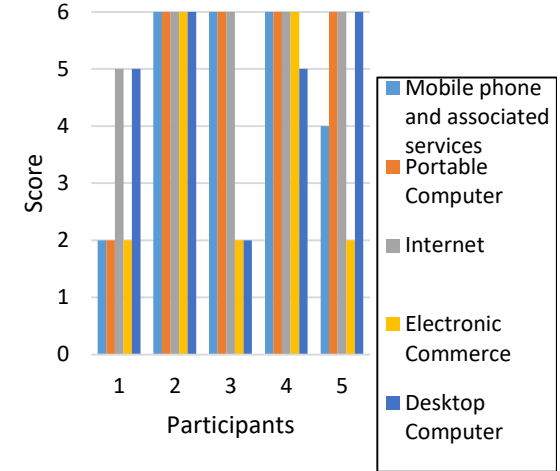
Q 1



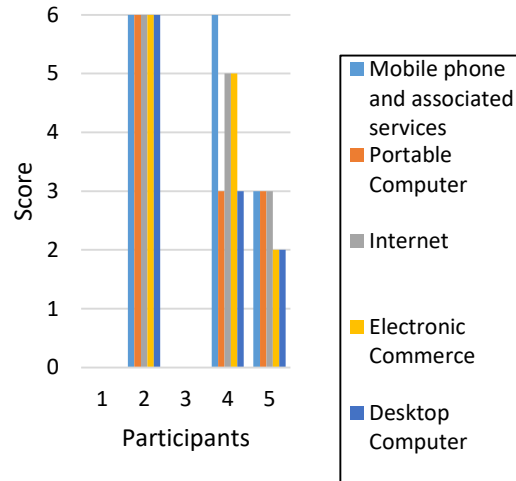
Q 2



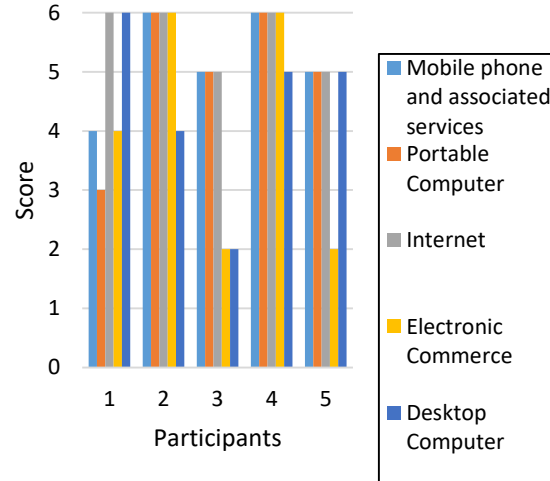
Q 3



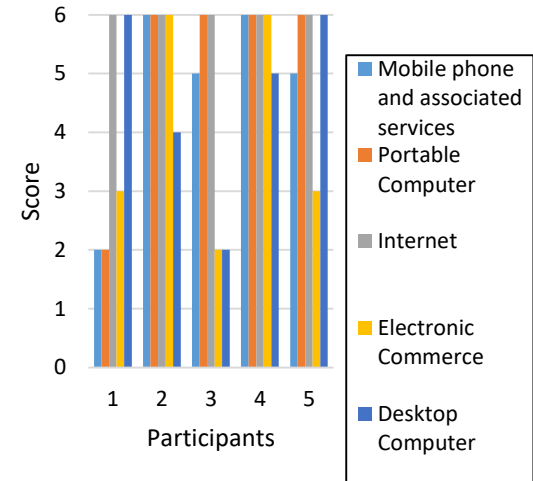
Q 4

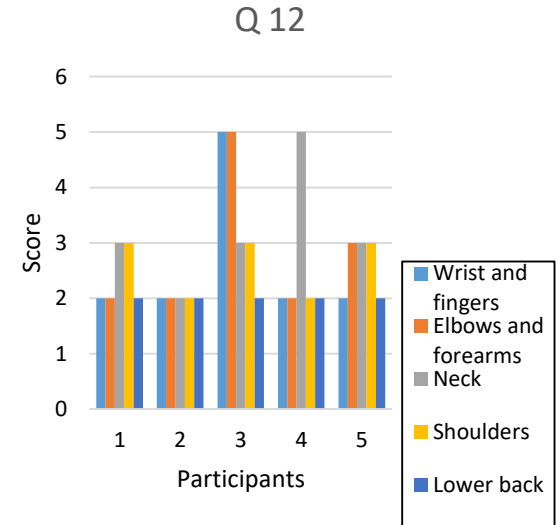
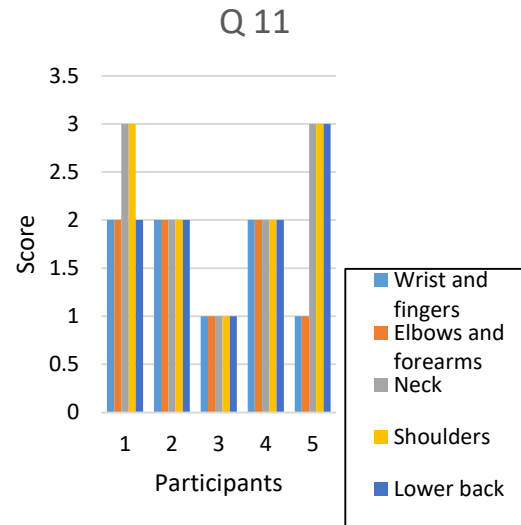
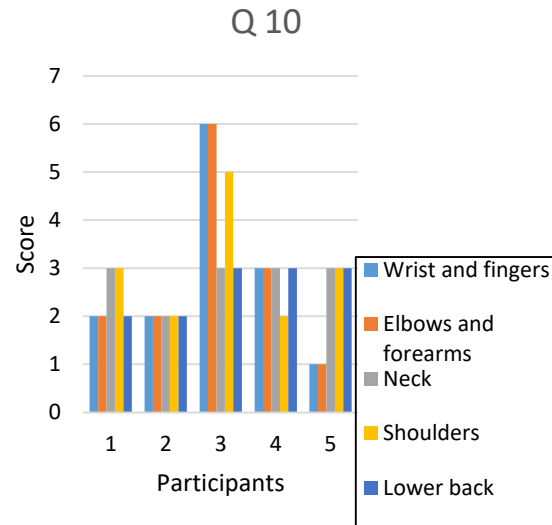
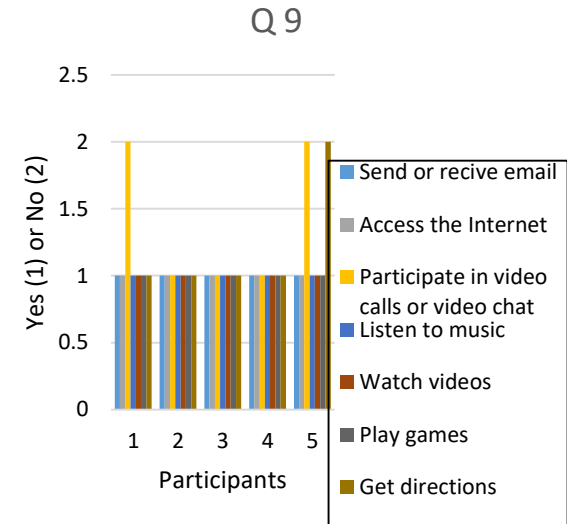
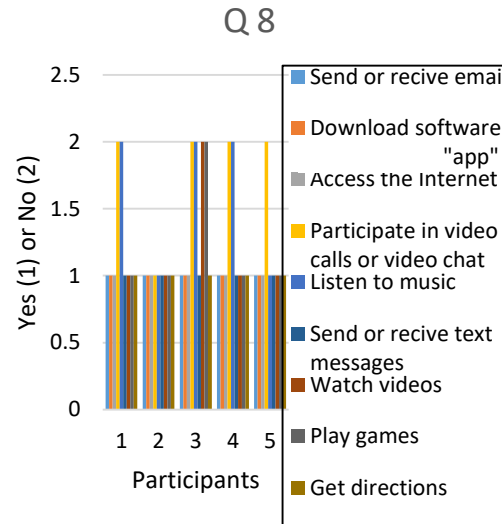
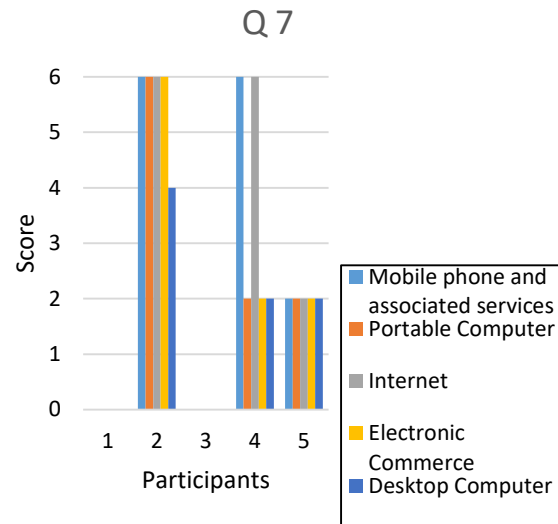


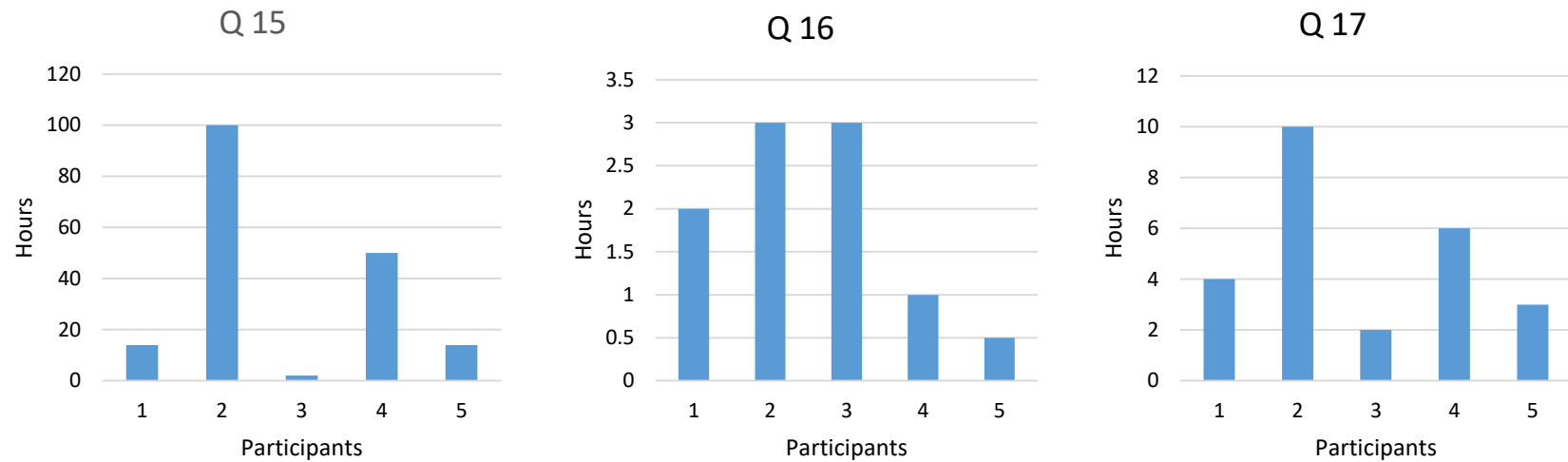
Q 5



Q 6







All graphs above correspond to the five healthy male responses to the questionnaire in Appendix B1.

Table 9: Healthy male responses to question 18.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
0 times					
1-2 times					
2-3 times					
3-4 times					
4-5 times					
5-6 times					
6-7 times					
7-8 times					
8-9 times					
≥10 Times	Yes	Yes	Yes	Yes	Yes

Table 10: Healthy male responses to question 19.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
0 times					
1-2 times	Yes				
2-3 times					
3-4 times					
4-5 times					
5-6 times					
6-7 times					
7-8 times				Yes	
8-9 times					
≥10 Times		Yes	Yes		Yes

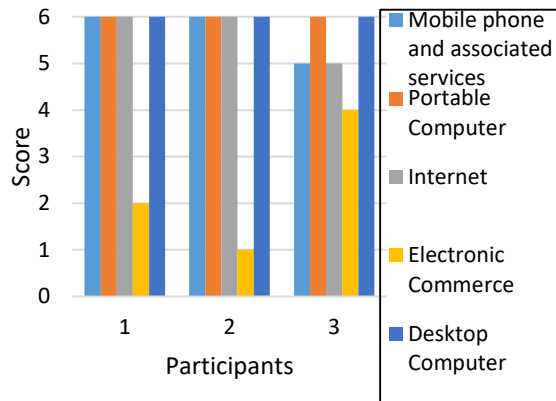
Table 11: Healthy male responses to question 20.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Saturday					
Sunday					
Monday					
Tuesday					
Wednesday					
Thursday					
Friday					

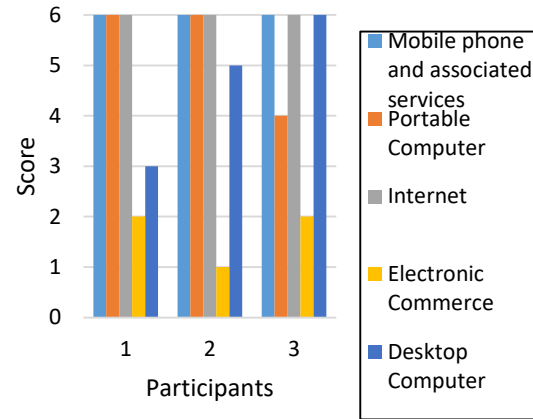
Table 12: Healthy male responses to question 21.

	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Saturday					
Sunday					
Monday	Yes				
Tuesday	Yes				
Wednesday	Yes				
Thursday					
Friday					

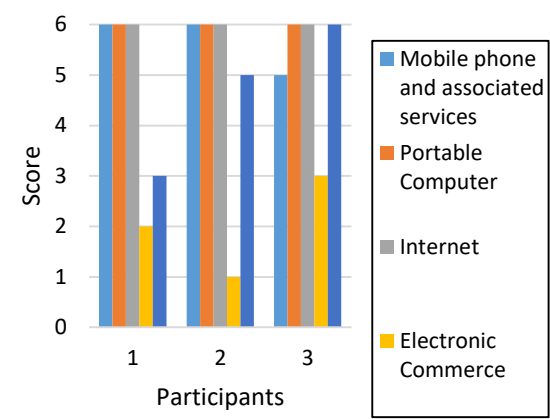
Q 1



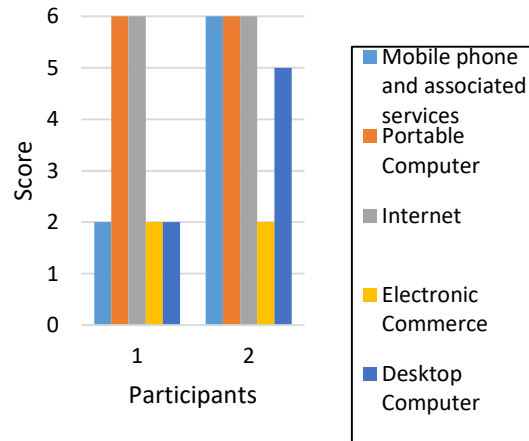
Q 2



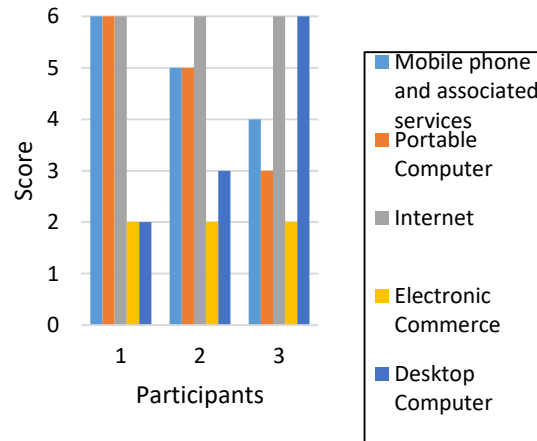
Q 3



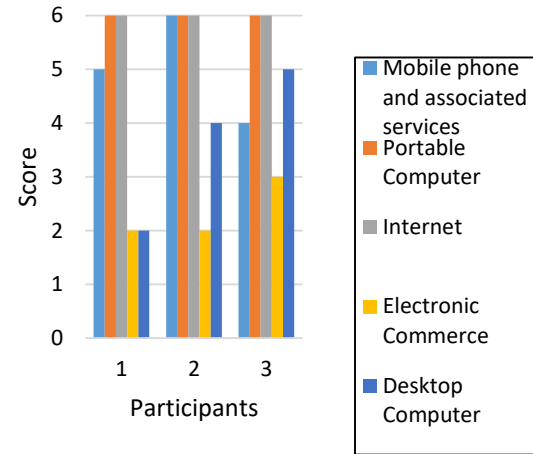
Q 4

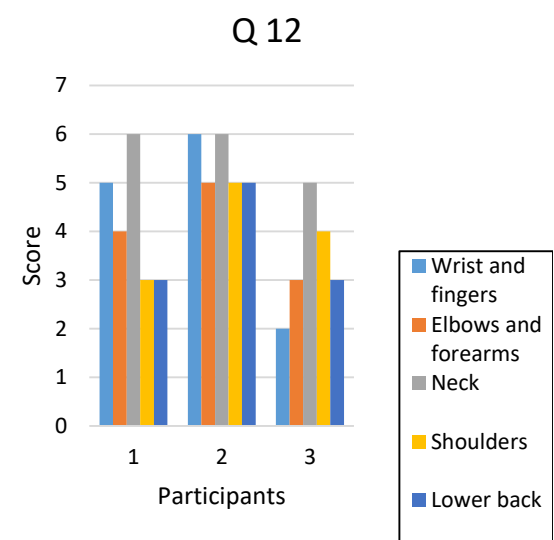
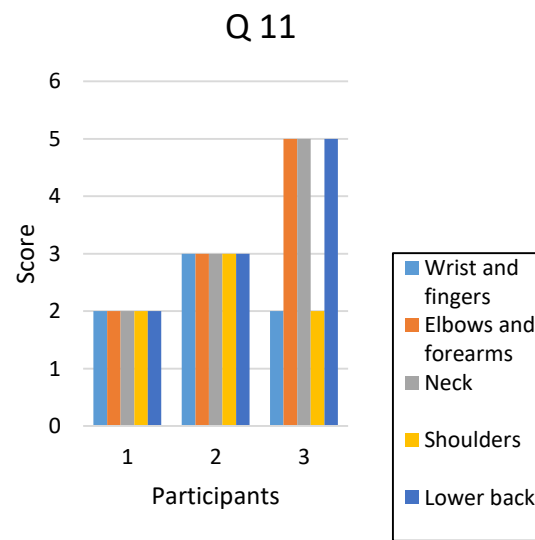
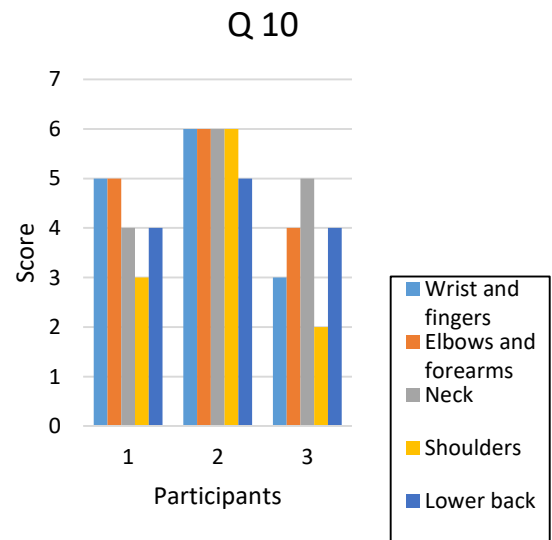
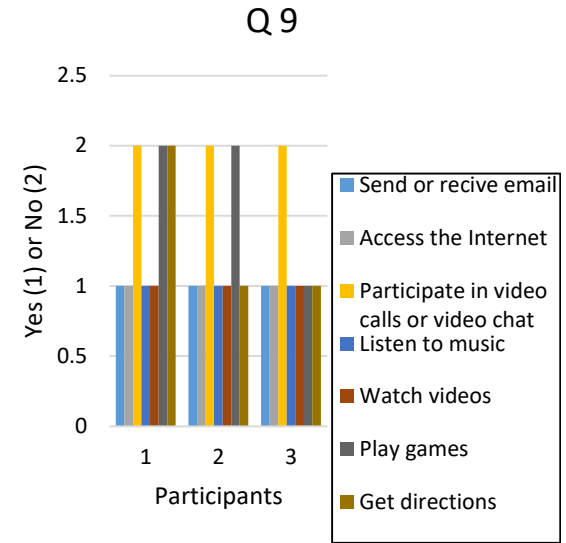
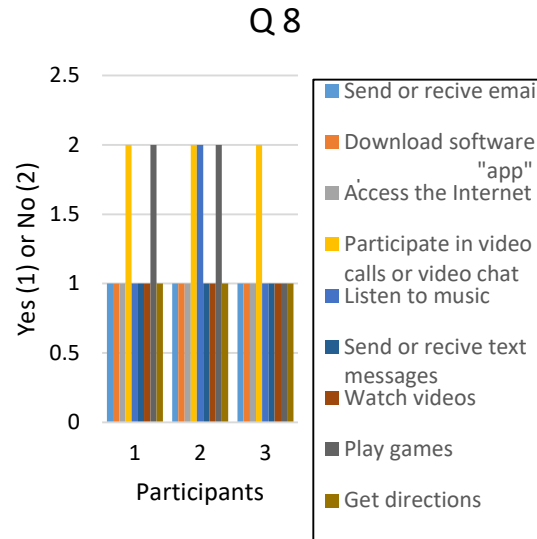
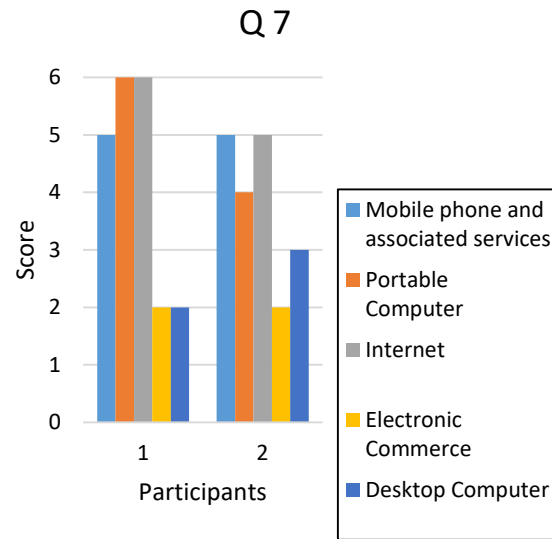


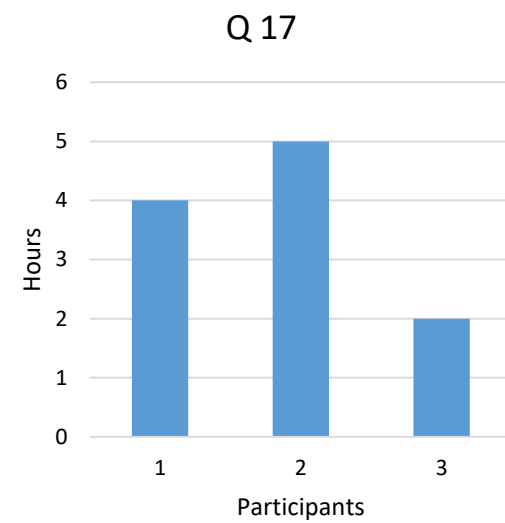
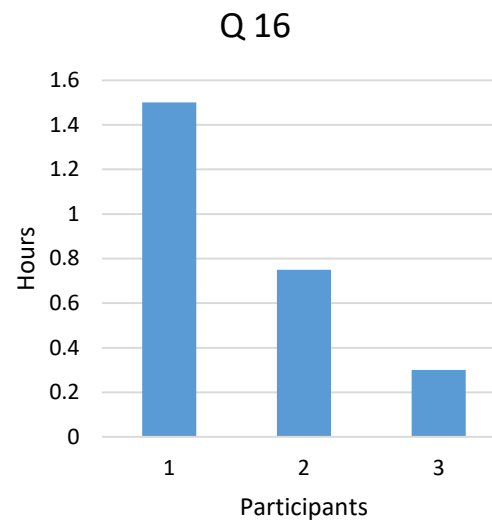
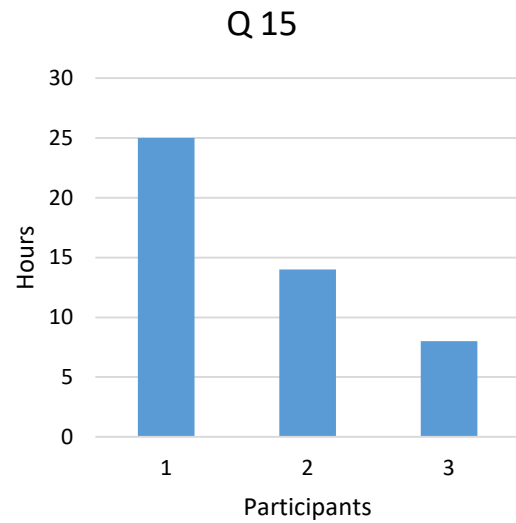
Q 5



Q 6







All graphs above correspond to the three subclinical male responses to the questionnaire in Appendix B1.

Table 13: NP male responses to question 18.

	Participant 1	Participant 2	Participant 3
0 times			
1-2 times			
2-3 times			
3-4 times			
4-5 times			
5-6 times			
6-7 times			
7-8 times			
8-9 times			
≥10 Times	Yes	Yes	Yes

Table 14: NP male responses to question 19.

	Participant 1	Participant 2	Participant 3
0 times			
1-2 times			
2-3 times			
3-4 times			
4-5 times			
5-6 times			
6-7 times			
7-8 times			
8-9 times			
≥10 Times			

Table 15: NP male responses to question 20.

	Participant 1	Participant 2	Participant 3
Saturday			
Sunday			
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			

Table 16: NP male responses to question 21.

	Participant 1	Participant 2	Participant 3
Saturday			
Sunday			
Monday			
Tuesday			
Wednesday			
Thursday			
Friday			

Table 17: Question 14 smartphone dimensions used by participants in this study.

Smartphones Used by Participants (Healthy Females)			
Dimensions (mm)	Screen Size (mm)	Weight (pounds)	Phone Type
124.4x59.2x8.97	101.6	0.2	iPhone 5c
129.9x65.9x11.6	114.3	0.3	Moto G
123x58.6x7.6	101.6	0.2	iPhone 5
136x70x7.3	127	0.2	Samsung Idol 2
0.3	139.7	0.3	LG G4
Smartphones Used By Participants (Subclinical NP Females)			
Dimensions (mm)	Screen Size (mm)	Weight (pound)	Phone Type
124.6x61.3x8.94	109.2	0.2	Samsung S4
152.9x75.9x8.9	139.7	0.3	Android One Smartphone
123.80x58.60x7.60	101.6	0.2	iPhone 5S
123x58.6x7.6	101.6	0.2	iPhone 5
124.4x59.2x8.97	101.6	0.2	iPhone 5c
Smartphones Used By Participants (Healthy Males)			
Dimensions (mm)	Screen Size (mm)	Weight (pound)	Phone Type
137.9x69.2x8.6	125.7	0.2	Nexus 5
153x78.6x8.5	144.7	0.3	Samsung Note 4
129.9x66.8x12.3	114.3	0.3	Motorola Moto "e" 2nd Generation
142x72.5x8.1	129.5	0.3	Samsung Galaxy S5
142x72.5x8.1	129.5	0.3	Samsung Galaxy S5
Smartphones Used By Participants (Subclinical NP Healthy Males)			
Dimensions (mm)	Screen Size (mm)	Weight (pound)	Phone Type
142x72.5x8.1	129.5	0.3	Samsung S5
138.1x67x6.9	119.3	0.2	iPhone 6
130x65.6x9	106.6	0.3	Blackberry Z10

Table 18: Question 13 laptop dimensions and brands used by the participants.

Laptops Used By Participants (Healthy Females)			
Dimensions (mm)	Screen Size (mm)	Weight (pounds)	Laptop Type
335.2x231.1x22.8	355.6	3.99	UOIT's Dell E5450
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd
245.1x372.8x31.7	355.6	5.56	UOIT's Lenovo ThinkPad T530
245.1x372.8x31.7	355.6	5.56	UOIT's Lenovo ThinkPad T530
Laptops Used By Participants (Subclinical NP Females)			
Dimensions (inches)	Screen Size (mm)	Weight (pounds)	Laptop Type
335.2x231.1x22.8	355.6	3.99	UOIT's Dell E5450
335.2x231.1x22.8	355.6	3.99	UOIT's Dell E5450
313.69x 226.5 x 18.0	13.3	3.48	Apple Macbook Pro
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd
Laptops Used By Participants (Healthy Males)			
Dimensions (inches)	Screen Size (mm)	Weight (pounds)	Laptop Type
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd
335.2x231.1x22.8	355.6	3.99	UOIT's Dell E5450
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd
Laptops Used By Participants (Subclinical NP Healthy Males)			

Dimensions (mm)	Screen Size (mm)	Weight (pounds)	Laptop Type
335.2x231.1x22.8	355.6	3.99	UOIT's Dell E5450
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd
334.7x22.8228.8	355.6	4.7	UOIT's Lenovo ThinkPad Model T440p Strd

Appendix B3: The Neck Disability Index Questionnaire

Neck Disability Index: This questionnaire is designed to help us better understand how your neck pain affects your ability to manage everyday life activities. Please mark in each section **ONE BOX** that applies to you. Although you may consider that two of the statement in any one section relate to you, please mark the box that **MOST CLOSELY** describes you present day situation.

SECTION 1 - PAIN INTENSITY

- ☐ I have no neck pain at the moment.
- ☐ The pain is very mild at the moment.
- ☐ The pain is moderate at the moment.
- ☐ The pain is fairly severe at the moment.
- ☐ The pain is very severe at the moment.
- ☐ The pain is the worst imaginable at the moment.

SECTION 2 - PERSONAL CARE

- ☐ I can look after myself normally without causing extra neck pain.
- ☐ I can look after myself normally, but it causes extra neck pain.
- ☐ It is painful to look after myself, and I am slow and careful
- ☐ I need some help but manage most of my personal care.
- ☐ I need help every day in most aspects of self -care.
- ☐ I do not get dressed. I wash with difficulty and stay in bed.

SECTION 3 – LIFTING

- ☐ I can lift heavy weights without causing extra neck pain.
- ☐ I can lift heavy weights, but it gives me extra neck pain.
- ☐ Neck pain prevents me from lifting heavy weights off the floor but I can manage if items are conveniently positioned, i.e. on a table.
- ☐ Neck pain prevents me from lifting heavy weights, but I can manage light weights if they are conveniently positioned
- ☐ I can lift only very light weights.
- ☐ I cannot lift or carry anything at all.

SECTION 4 – READING

- ☐ I can read as much as I want with no neck pain.
- ☐ I can read as much as I want with slight neck pain.
- ☐ I can read as much as I want with moderate neck pain.
- ☐ I can't read as much as I want because of moderate neck pain.
- ☐ I can't read as much as I want because of severe neck pain.
- ☐ I can't read at all.

SECTION 5 – HEADACHES

- ☐ I have no headaches at all.
- ☐ I have slight headaches that come infrequently.
- ☐ I have moderate headaches that come infrequently.
- ☐ I have moderate headaches that come frequently.
- ☐ I have severe headaches that come frequently.

- ☐ I have headaches almost all the time.

SECTION 6 – CONCENTRATION

- ☐ I can concentrate fully without difficulty.
☐ I can concentrate fully with slight difficulty.
☐ I have a fair degree of difficulty concentrating.
☐ I have a lot of difficulty concentrating.
☐ I have a great deal of difficulty concentrating.
☐ I can't concentrate at all.

SECTION 9 – SLEEPING

- ☐ I have no trouble sleeping.
☐ My sleep is slightly disturbed for less than 1 hour.
☐ My sleep is mildly disturbed for up to 1-2 hours.
☐ My sleep is moderately disturbed for up to 2-3 hours.
☐ My sleep is greatly disturbed for up to 3-5 hours.
☐ My sleep is completely disturbed for up to 5-7 hours.

SECTION 7 –WORK

- ☐ I can do as much work as I want.
☐ I can only do my usual work, but no more.
☐ I can do most of my usual work, but no more.
☐ I can't do my usual work.
☐ I can hardly do any work at all.
☐ I can't do any work at all.

SECTION 8 – DRIVING

- ☐ I can drive my car without neck pain.
☐ I can drive my car with only slight neck pain.
☐ I can drive as long as I want with moderate neck pain.
☐ I can't drive as long as I want because of moderate neck pain.
☐ I can hardly drive at all because of severe neck pain.
☐ I can't drive my car at all because of neck pain.

SECTION 10 – RECREATION

- ☐ I am able to engage in all my recreational activities with no neck pain at all.
☐ I am able to engage in all my recreational activities with some neck pain.
☐ I am able to engage in most, but not all of my recreational activities because of pain in my neck.
☐ I am able to engage in a few of my recreational activities because of neck pain.
☐ I can hardly do recreational activities due to neck pain.
☐ I can't do any recreational activities due to neck pain.

PATIENT NAME _____ **DATE** _____
SCORE _____ **[50] COPYRIGHT: VERNON H & HAGINO C, 1991**

SCORING TECHNIQUE FOR NECK DISABILITY INDEX

1. Each of the 10 sections is scored separately (0 to 5 points each) and then added up (max. total= 50).

EXAMPLE:

Section 1. Pain Intensity Point Value

- A. _____ I have no pain at the moment (0)
 - B. _____ The pain is very mild at the moment (1)
 - C. _____ The pain is moderate at the moment (2)
 - D. _____ The pain is fairly severe at the moment (3)
 - E. _____ The pain is very severe at the moment (4)
 - F. _____ The pain is the worst imaginable (5)
- 2.

If all 10 sections are completed, simply double the patients score.

3. If a section is omitted, divide the patient's total score by the number of sections completed times 5.

FORMULA: $\frac{\text{PATIENT'S SCORE}}{\# \text{ OF SECTIONS COMPLETED} \times 5} \times 100 = \text{ \% DISABILITY}$

EXAMPLE:

If 9 of 10 sections are completed, divide the patient's score by $9 \times 5 = 45$; if.....

Patient's Score: 22

Number of sections completed: 9 ($9 \times 5 = 45$)

$22/45 \times 100 = 48 \%$ disability

Appendix B4: Chronic Pain Grade Scale

Overview: The severity of chronic pain can be graded based on its characteristics and its impact on a person's activities.

Questions [text slightly modified from Appendix page 147]

(1) How would you rate your pain on a 0-10 scale at the present time (right now)? [Pain Right Now]

- responses 0 to 10
- 0 = no pain
- 10 = pain as bad as it could be

(2) During the past 6 months how intense was your worst pain? [Worst Pain]

- responses 0 to 10
- 0 = no pain
- 10 = pain as bad as it could be

(3) During the past 6 months on the average how intense was your pain? (That is your usual pain at times you were experiencing pain.) [Average Pain]

- responses 0 to 10
- 0 = no pain
- 10 = pain as bad as it could be

(4) About how many days in the past 6 months have you been kept from your usual activities (work school or housework) because of your pain? [Disability Days]

- response the total number of days disabled
- points assigned below

5) In the past 6 months how much has the pain interfered with your daily activities? [Daily Activities]

- responses 0 to 10
- 0 = no interference
- 10 = unable to carry on any activities

(6) In the past 6 months how much has the pain changed your ability to take part in recreational social and family activities? [Social Activities]

- responses 0 to 10 • 0 = no change
- 10 = extreme change

(7) In the past 6 months how much has the pain changed your ability to work (including housework)? [Work Activities]

- responses 0 to 10
- 0 = no change
- 10 = extreme change

characteristic pain intensity = (((response question 1) + (response question 2) + (response question 3)) / 3) * 10

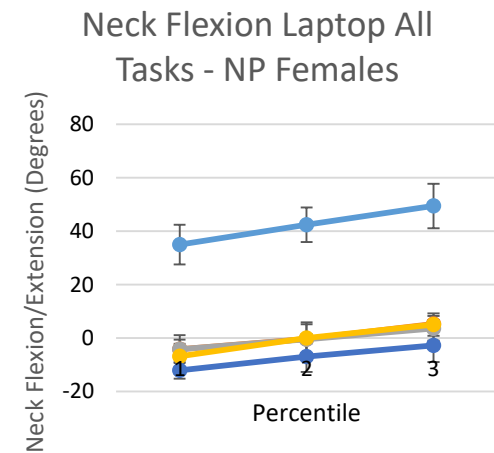
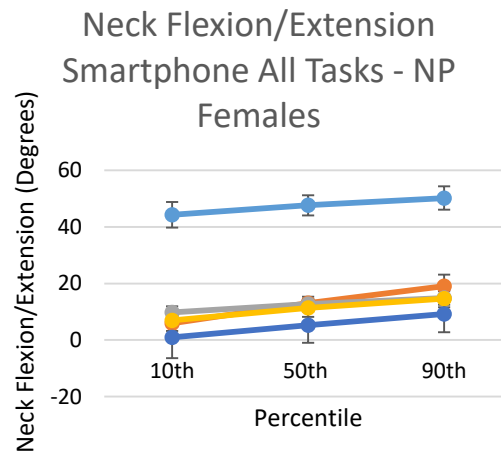
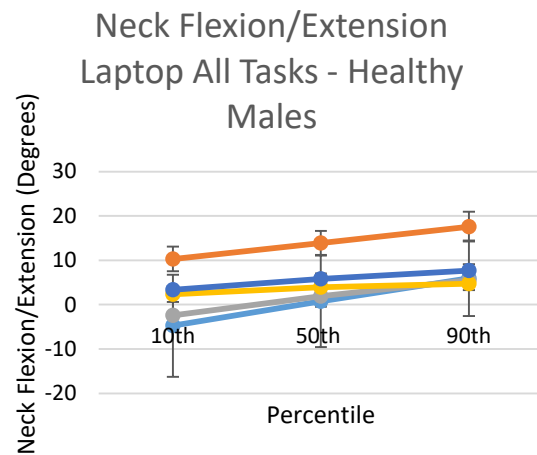
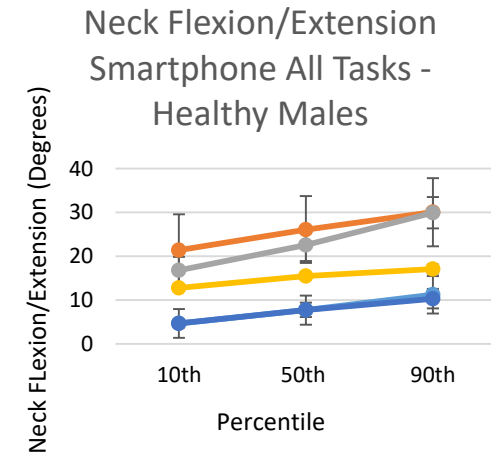
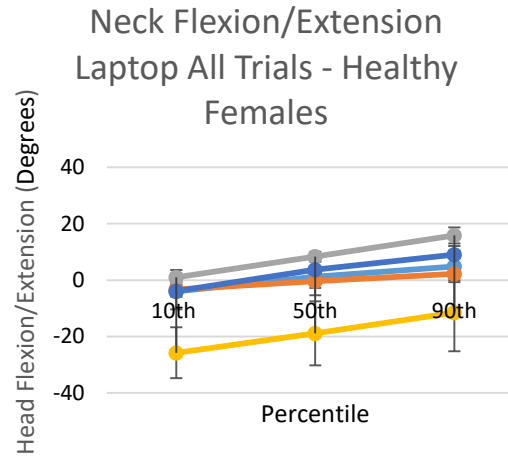
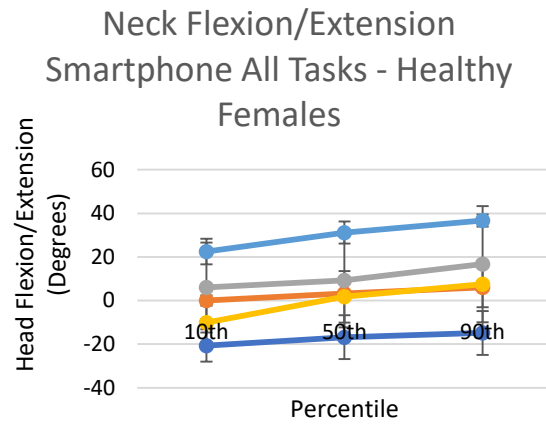
disability score = (((response question 5) + (response question 6) + (response question 7)) / 3) * 10

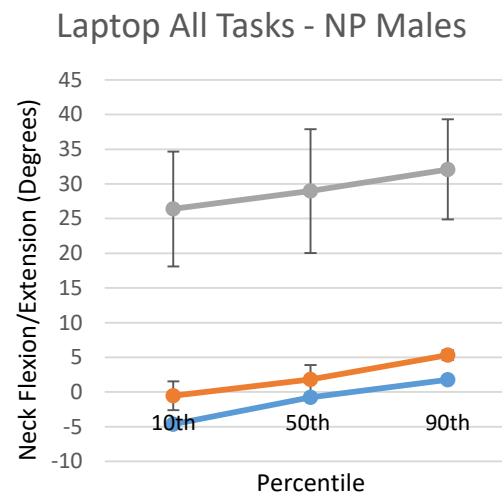
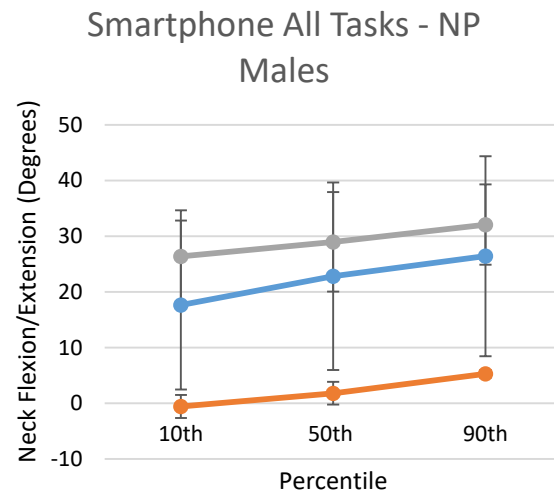
disability points = (points for disability days) + (points for disability score)

Parameter	Finding	Points
disability days from question 4	0 - 6 days	0
	7 – 14 days	1
	15 - 30 days	2
	>= 31 days	3
disability score (above)	0 - 29	0
	30 - 49	1
	40 - 69	2
	>= 70	3

	Type	Grade
Interpretation Findings		
no pain problems for the prior 6 months	pain free	0
characteristic pain intensity < 50 disability points < 3	low disability low intensity	I
characteristic pain intensity ≥ 50 disability points < 3	low disability high intensity	II
disability points 3 or 4	high disability moderately limiting	III
disability points 5 or 6	high disability severely limiting	IV

Appendix C1: Kinematic Graphs





Appendix C2: Discomfort Score Results (Laptop and Smartphone)

The following results contain significant and non-significant findings. These results are presented here in the appendix instead of within the manuscript because these findings were not the focus of the manuscript.

Laptop

Posterior head: There was a significant effect of time ($F_{5,70} = 3.009$, $P=0.016$) for the posterior head region during laptop tasks (Figure 7 A). Ten minutes into the condition had a significantly lower average discomfort score ($0.7 \text{ mm} \pm 0.7 \text{ mm}$) than later in the condition (20 minutes, $2.0 \text{ mm} \pm 1.0 \text{ mm}$; 30 minutes, $3.3 \text{ mm} \pm 1.7 \text{ mm}$; 40 minutes, $3.4 \text{ mm} \pm 1.6 \text{ mm}$; 50 minutes $4.3 \text{ mm} \pm 2.1 \text{ mm}$; and 60 minutes $3.3 \text{ mm} \pm 1.6 \text{ mm}$). There was a progressive increase in posterior head discomfort across all groups, except at 60 minutes. While not significant, subclinical NP females had higher discomfort scores than the other groups (healthy females, healthy males and subclinical males).

Posterior Thoracic Region: The posterior thoracic region had a time by sex interaction ($F_{5,70} = 2.755$, $P = 0.025$) (Figure 7 D). In general, the healthy and subclinical females had higher scores than the healthy and subclinical males (see Figure 7 D). When comparing females and males, females in general increased throughout the hour laptop task (peaking at 35 mm for healthy females and 26 mm for subclinical females) while all males remained below the 10 mm discomfort score. Females had a higher mean score ($4.2 \text{ mm} \pm 1.3 \text{ mm}$) than males ($0.8 \text{ mm} \pm 1.5 \text{ mm}$). The mean scores for time steadily increased over the six time intervals (10 minute mean score ($1.1 \text{ mm} \pm 0.6 \text{ mm}$), 20 minutes mean score ($1.4 \text{ mm} \pm 0.8 \text{ mm}$), 30 minutes ($2.3 \text{ mm} \pm 1.0 \text{ mm}$), 40 minutes ($3.3 \text{ mm} \pm 1.2 \text{ mm}$), 50 minutes ($3.4 \text{ mm} \pm 1.8 \text{ mm}$) and 60 minutes ($3.6 \text{ mm} \pm 1.6 \text{ mm}$)).

Posterior Lumbar/Sacral Region: The posterior lumbar/sacral region had a significant effect of time ($F_{5,70} = 3.123$, $P = 0.013$) (Figure 7 E). Healthy females' discomfort scores peaked around 20 mm of

discomfort at 40 minutes and was approximately 6 mm at 60 minutes. Subclinical females' discomfort scores peaked around 54 mm at 60 minutes. Healthy males' discomfort scored peaked at 20 mm at 60 minutes while subclinical males' discomfort score peaked at approximately 17 mm at 50 minutes. The mean scores for the six time intervals increased for the first 30 minutes of the laptop tasks before decreasing for the other half (10 minute interval mean score was $(0.9 \text{ mm} \pm 0.6 \text{ mm})$, 20 minute mean score $(2.6 \text{ mm} \pm 1.3 \text{ mm})$, 30 minute mean score $(5.3 \text{ mm} \pm 1.4 \text{ mm})$, 40 minute mean score $(4.9 \text{ mm} \pm 1.8 \text{ mm})$, 50 minutes mean score $(2.8 \text{ mm} \pm 1.5 \text{ mm})$ and 60 minutes $(3.9 \text{ mm} \pm 1.2 \text{ mm})$).

Frequency usage questionnaire for the posterior shoulders were reported as the following: Two of the five healthy females reported an ache, pain or numbness in their lower back that they associated with laptop use. All subclinical females associated an ache, pain or numbness within their lower back with laptop computer use. Three out of the five healthy males reported an ache, pain or numbness of their lower back when using their laptop computers.

Posterior Right Hand and Forearm: The posterior right forearm and hand had a significant main effect of sex ($F_{5,70} = 9.620$, $P = 0.008$), with males having a greater mean score $(4.3 \text{ mm} \pm 1.0 \text{ mm})$ than females $(0.4 \text{ mm} \pm 0.8 \text{ mm})$. There was also a sex by group interaction ($F_{5,70} = 5.396$, $P = 0.036$), with healthy females having a higher mean score $(0.5 \text{ mm} \pm 1.2 \text{ mm})$ than the subclinical females $(0.2 \text{ mm} \pm 1.2 \text{ mm})$ but a lower mean score compared to both the healthy males $(1.5 \text{ mm} \pm 1.2 \text{ mm})$ and subclinical males $(7.2 \text{ mm} \pm 1.5 \text{ mm})$ (Figure 7 F).

Frequency usage questionnaire for the posterior shoulders were reported as the following: Three of the five subclinical NP females reported an ache, pain or numbness in their wrists, fingers, elbows and forearms that they associated with laptop use. Two of the five healthy males reported an ache, pain or numbness in their wrists, fingers, elbows and forearms when using their laptop computers. All three

subclinical NP males reported an ache, pain or numbness within their wrist, fingers, elbows and forearms that they associated with laptop use.

Smartphone

Posterior Head: The posterior head had a significant main effect of time ($P = 0.002$). The discomfort scores increased over the six time intervals (10 minute mean score was $(0.9 \text{ mm} \pm 0.5 \text{ mm})$, 20 minutes $(1.8 \text{ mm} \pm 1.0 \text{ mm})$, 30 minutes $(2.2 \text{ mm} \pm 1.2 \text{ mm})$, 40 minutes $(6.0 \text{ mm} \pm 3.3 \text{ mm})$, 50 minutes $(6.1 \text{ mm} \pm 1.8 \text{ mm})$ and 60 minutes $(6.9 \text{ mm} \pm 2.1 \text{ mm})$). A time by group interaction ($F_{5,70} = 3.963$, $P = 0.003$) demonstrated that subclinical participants' discomfort scores increased more than healthy participants. There was also a significant difference between groups when comparing healthy and subclinical NP participants over time ($P = 0.021$). Subclinical participants had a higher mean discomfort score $(7.9 \text{ mm} \pm 2.3 \text{ mm})$ than healthy participants $(0.1 \text{ mm} \pm 1.1 \text{ mm})$ (Figure 8 A).

Posterior Neck: There were no significant differences found for the posterior neck for the smartphone tasks.

Frequency usage questionnaire for the posterior shoulders were reported as the following: Two of the five healthy females reported an ache, pain or numbness within their neck with smartphone use. All five of the subclinical NP females reported an ache, pain or numbness in their necks with smartphone use. Two of the five healthy males associated an ache, pain or numbness in their necks with smartphone use. All three subclinical NP males reported an ache, pain or numbness in their necks associated with smartphone use.

Thoracic Region: There was a significant main effect of sex for the posterior thoracic region ($P = 0.037$), with females having a higher mean score $(3.7 \text{ mm} \pm 1.1 \text{ mm})$ than males $(-0.3 \text{ mm} \pm 1.3 \text{ mm})$ (Figure 8 B).

Posterior Lumbar/Sacral Region: The posterior lumbar/sacral region had a significant difference in time ($P = 0.003$) (Figure 8 C). The mean discomfort scores increased over the six time intervals (10 minutes mean discomfort score was $1.3 \text{ mm} \pm 0.7 \text{ mm}$), 20 minutes ($-0.2 \text{ mm} \pm 1.4 \text{ mm}$), 30 minutes ($2.4 \text{ mm} \pm 2.7 \text{ mm}$), 40 minutes ($2.8 \text{ mm} \pm 3.1 \text{ mm}$), 50 minutes ($6.1 \text{ mm} \pm 3.8 \text{ mm}$), and 60 minutes ($7.0 \text{ mm} \pm 3.8 \text{ mm}$). Healthy females had the highest mean score ($7.7 \text{ mm} \pm 4.4 \text{ mm}$), followed by subclinical females ($2.7 \text{ mm} \pm 4.4 \text{ mm}$) which were greater than the healthy males ($0.5 \text{ mm} \pm 4.4 \text{ mm}$) and subclinical males ($0.3 \text{ mm} \pm 5.7 \text{ mm}$). These differences were not significant, however clear differences are demonstrated (Figure 8 C).

Frequency usage questionnaire for the posterior shoulders were reported as the following: One of the five healthy females reported an ache, pain or numbness within their lower back with smartphone use. All five subclinical NP females reported an ache, pain or numbness in their lower backs that they associated with smartphone use. None of the healthy males reported an ache, pain or numbness within their lower backs when using their smartphone. All three subclinical NP males associated an ache, pain or numbness in their shoulders with using their smartphone computer.

Posterior Right Hand and Forearm: The posterior right forearm and hand had a significant main effect of time ($P = 0.003$) (Figure 8 D). In general, the discomfort scores increased as time progressed, but no specific times were found to be significant. Subclinical participants had a greater mean score ($9.7 \text{ mm} \pm 3.4 \text{ mm}$) than healthy participants ($1.2 \text{ mm} \pm 2.9 \text{ mm}$), however, surprisingly, this was not significant. Males also had greater mean scores ($7.9 \text{ mm} \pm 3.4 \text{ mm}$) than females ($3.0 \text{ mm} \pm 2.9 \text{ mm}$), and this was also not significant (Figure 8 D).

Frequency usage questionnaire for the posterior shoulders were reported as the following: One of the five healthy females reported an ache, pain or numbness within their wrists, fingers, elbows, and forearms with smartphone use. Four of the five subclinical NP females reported an ache, pain or

numbness within their wrist and fingers with smartphone use. Two out of five subclinical NP females reported elbow and forearm aches, pains or numbness with smartphone use. One out of the five healthy males reported an ache, pain or numbness in their wrist and fingers with smartphone use. Two out of the five healthy males reported an ache, pain or numbness within their elbows and forearms when using their smartphone. Two out of the three subclinical NP males reported an ache, pain or numbness in their wrist and fingers that they associated with smartphone use. All three of the subclinical NP males reported an ache, pain or numbness within their elbows and forearms that they associated with smartphone use.

Appendix C3: Surface Electromyography Results (Laptop and Smartphone)

The following results contain significant and non-significant findings. These results are presented here in the appendix instead of within the manuscript because these findings were not deemed important to the manuscript.

Laptop

APDF Results

APDF – 10th percentile: There were no significant differences found for the 10th percentile APDF for any of the muscles measured. However, for the left CE, females had a mean muscle activity of $6.1 \pm 2.2\%$ MVE while males had a mean of $9.0 \pm 2.5\%$ MVE. The healthy group had a mean of $5.2 \pm 2.2\%$ MVE while the NP group had a mean of $9.9 \pm 2.5\%$ MVE. For the right CE, females had a mean muscle activity of $7.1 \pm 1.4\%$ MVE while males had a mean of $4.8 \pm 1.6\%$ MVE. Healthy participants had a mean of $5.5 \pm 1.4\%$ MVE while subclinical NP participants had a mean of $6.3 \pm 1.6\%$ MVE. For the left UT, females had a mean muscle activity of $3.0 \pm 1.0\%$ MVE while males had a mean of $1.5 \pm 1.2\%$ MVE. Healthy participants had a mean of $1.8 \pm 1.0\%$ MVE while subclinical NP participants had a mean of $2.7 \pm 1.2\%$ MVE. For the right UT, females had a mean muscle activity of $2.8 \pm 1.1\%$ MVE while males had a mean of $1.7 \pm 1.3\%$ MVE. Healthy participants had a mean of $2.4 \pm 1.1\%$ MVE while subclinical NP participants had a mean of $2.1 \pm 1.3\%$ MVE. For the left AD, females had a mean muscle activity of $3.1 \pm 1.4\%$ MVE while males had a mean of $1.6 \pm 1.7\%$ MVE. Healthy participants had a mean of $1.4 \pm 1.4\%$ MVE while subclinical NP participants had a mean of $2.1 \pm 1.3\%$ MVE. For the right AD, females had a mean muscle activity of $1.2 \pm 0.5\%$ MVE while males had a mean of $0.9 \pm 0.5\%$ MVE. Healthy participants had a mean of $0.7 \pm 0.5\%$ MVE while subclinical NP participants had a mean of $1.4 \pm 0.5\%$ MVE.

APDF – 50th percentile: There were no significant differences found for the 50th percentile APDF for any of the muscles measured. However, for the left CE, females had a mean muscle activity of $8.5 \pm$

2.5% MVE while males had a mean of $11.6 \pm 2.9\%$ MVE. The healthy group had a mean of $7.3 \pm 2.5\%$ MVE while the NP group had a mean of $12.8 \pm 2.9\%$ MVE. For the right CE, females had a mean muscle activity of $3.0 \pm 1.0\%$ MVE while males had a mean of $1.5 \pm 1.2\%$ MVE. Healthy participants had a mean of $1.8 \pm 1.0\%$ MVE while subclinical NP participants had a mean of $2.7 \pm 1.2\%$ MVE. For the left UT, females had a mean muscle activity of $5.6 \pm 1.5\%$ MVE while males had a mean of $1.8 \pm 1.7\%$ MVE. Healthy participants had a mean of $3.8 \pm 1.5\%$ MVE while subclinical NP participants had a mean of $3.6 \pm 1.7\%$ MVE. For the left UT, females had a mean muscle activity of $5.0 \pm 1.5\%$ MVE while males had a mean of $2.1 \pm 1.7\%$ MVE. Healthy participants had a mean of $3.5 \pm 1.5\%$ MVE while subclinical NP participants had a mean of $3.6 \pm 1.7\%$ MVE. For the left AD, females had a mean muscle activity of $4.4 \pm 1.8\%$ MVE while males had a mean of $2.3 \pm 2.1\%$ MVE. Healthy participants had a mean of $2.3 \pm 1.8\%$ MVE while subclinical NP participants had a mean of $4.4 \pm 2.1\%$ MVE. For the right AD, females had a mean muscle activity of $1.7 \pm 0.5\%$ MVE while males had a mean of $1.3 \pm 0.6\%$ MVE. Healthy participants had a mean of $1.1 \pm 0.5\%$ MVE while subclinical NP participants had a mean of $1.9 \pm 0.6\%$ MVE.

Smartphone

APDF Results

APDF – 10th percentile

There were no significant differences found for the 10th percentile APDF for any of the muscles measured. However, for the left cervical extensors (left CE), female muscle activity was $7.4 \pm 1.7\%$ MVE while males was $4.9 \pm 2.0\%$ MVE. Overall, the healthy group had less muscle activity ($4.5 \pm 1.7\%$ MVE) than the NP group ($7.8 \pm 2.0\%$ MVE). For the right cervical extensors (right CE), female muscle activity ($8.2 \pm 1.9\%$ MVE) was greater than males ($6.00 \pm 2.2\%$ MVE). Healthy participants had a mean

of $7.3 \pm 1.8\%$ MVE while subclinical NP participants had a mean of $6.8 \pm 2.2\%$ MVE. For the left upper trapezius (left UT) females had a mean of $6.0 \pm 2.3\%$ MVE while males had a mean of $0.86 \pm 2.7\%$ MVE. Healthy participants had a mean of $2.5 \pm 2.3\%$ MVE while subclinical NP participants had a mean of $4.3 \pm 2.7\%$ MVE. For the right upper trapezius (right UT) females had a mean of $6.0 \pm 2.4\%$ MVE while males had a mean of $1.7 \pm 2.8\%$ MVE. Healthy participants had a mean of $2.7 \pm 2.4\%$ MVE while subclinical NP participants had a mean of $5.0 \pm 2.8\%$ MVE. For the left anterior deltoid (left AD) females had a mean of $1.5 \pm 0.4\%$ MVE while males had a mean of $1.7 \pm 0.4\%$ MVE. Healthy participants had a mean of $1.3 \pm 0.4\%$ MVE while subclinical NP participants had a mean of $1.8 \pm 0.4\%$ MVE. For the right anterior deltoid (right AD) females had a mean of $1.2 \pm 0.5\%$ MVE while males had a mean of $0.9 \pm 0.5\%$ MVE. Healthy participants had a mean of $0.7 \pm 0.5\%$ MVE while subclinical NP participants had a mean of $1.4 \pm 0.5\%$ MVE.

APDF – 50th percentile

For the left AD, females had a mean muscle activity of $1.9 \pm 0.4\%$ MVE while males had a mean of $1.8 \pm 0.5\%$ MVE. Healthy participants had a mean muscle activity of $1.7 \pm 0.4\%$ MVE while subclinical NP participants had a mean of $2.1 \pm 0.5\%$ MVE. For the right AD, females had a mean muscle activity of $3.7 \pm 2.0\%$ MVE while males had a mean of $1.1 \pm 2.3\%$ MVE. Healthy participants had a mean muscle activity of $3.7 \pm 2.0\%$ MVE while subclinical NP participants had a mean of $1.1 \pm 2.3\%$ MVE.

APDF – 90th percentile

For the left AD, females had a mean of $3.2 \pm 0.8\%$ MVE while males had a mean of $2.2 \pm 1.0\%$ MVE. Healthy participants had a mean of $2.9 \pm 0.8\%$ MVE while subclinical NP participants had a mean of $2.5 \pm 1.0\%$ MVE. For the right AD, females had a mean muscle activity of $3.3 \pm 1.2\%$ MVE

while males had a mean of $1.6 \pm 1.3\%$ MVE. Healthy participants had a mean of $3.3 \pm 1.2\%$ MVE while subclinical NP participants had a mean of $1.6 \pm 1.3\%$ MVE.

Appendix C4: Gaps Surface Electromyography Results (Laptop and Smartphone)

Laptop

Gaps Analysis: There were no significant differences found for total gap time. There was a significant difference for the number of gaps for the right AD ($P=0.042$, $F_{1,14} = 5.001$). Healthy participants had a greater number of times below the 2% threshold (124.6 ± 36.3) than subclinical participants (86.0 ± 41.9) (Figure 15).

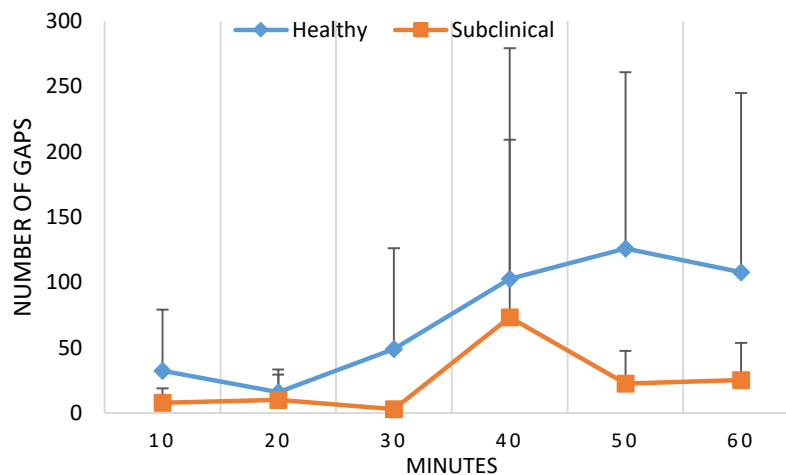


Figure 14: Number of gaps of healthy and subclinical NP participants for the right anterior deltoid.

There were no significant differences found within the average gap time category.

Smartphone

Gaps Analysis: There was a significant sex difference for the left AD ($P=0.012$, $F_{1,14} = 8.336$) with females having double the number of gaps (40.8 ± 17.1) than males (20.4 ± 19.7) (Figure 15).

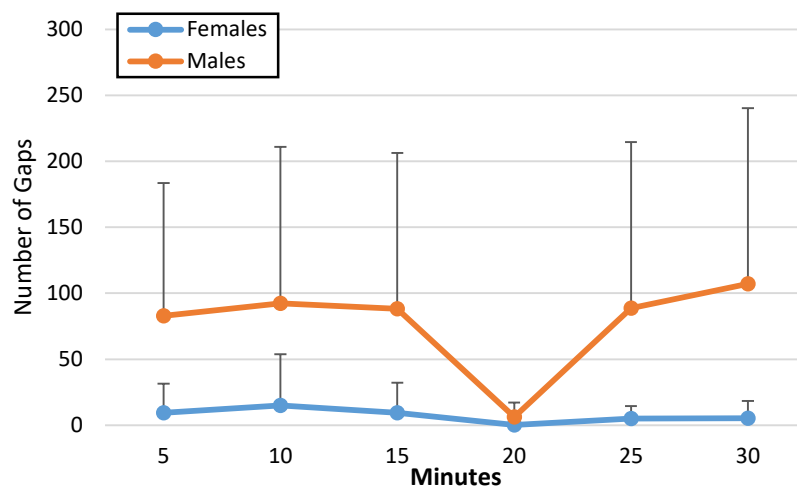


Figure 15: Number of gaps during the smartphone task for the left anterior deltoid.

Appendix D1: Neck Disability Index Questionnaire Validity and Reliability

The NDI is a modified form of the Oswestry Disability Index (ODI) (Pietrobon, Coeytaux, Carey, Richardson, & DeVellis, 2002; Vernon & Mior, 1991). Item content of NDI assesses various levels of neck pain, headache, personal care, work, driving, lifting, recreational activities, reading, sleeping, and concentration with each item including six possible responses each representing increasing levels of disability (Hains, Waalen, & Mior, 1998).

The NDI is scored in a similar way to the ODI. Each item has an ordinal response scale with six potential responses, each describing a greater degree of disability, ranging from 0 to 5. Scores are summed to provide a total score ranging from 0 (no disability) to 50 (maximum disability) (Vernon & Mior, 1991). The NDI's total percentage score can be found by multiplying the total summed score by two and expressing the result as a percentage (Hains et al., 1998). Clinical significance of NDI scores has been reported: 0 – 4 (0 - 8%) no neck pain, 5 - 14 (8 – 28%) mild neck pain, 15 – 24 (28 – 48%) moderate neck pain, 25 – 34 (48 – 68%) severe neck pain, and > 35 (>68%) complete neck pain (Vernon & Mior, 1991).

According to Pietrobon et al. (2002) it is the property that determines whether or not a scale is measuring something in a consistent, reproducible manner. The NDI has an excellent internal consistency with a Cronbachs alpha value of 0.80 being reported (Vernon & Mior, 1991). In a larger sample Hains et al (1998) reported a Cronbachs alpha of 0.92. Since internal consistency measures whether the items on a scale are correlated or not (Pietrobon et al., 2002) the Cronbachs alpha scores indicate that the NDI items are correlated measuring different aspects of the same trait (Hains et al., 1998). Test-retest reliability was determined from a sample of whiplash patients who had a retest period of 2 days and stability was found to be acceptable with a Pearsons correlation coefficient calculated to be 0.89 ($p < 0.05$) (Vernon & Mior, 1991). The effects of age and gender were not found to be

statistically significant indicating the questionnaire is applicable to a large population range (Vernon & Mior, 1991).

Validity provides an indication as to whether a scale is measuring the construct it is intended to or some other related construct (Pietrobon et al., 2002). The NDI content validity was researched. The NDI is a one dimensional scale as has been identified by factor analysis where a single factor has been shown to account for 59-65% of the total variance with the scale measuring the physical aspect of pain disability (Hains et al., 1998; Pietrobon et al., 2002). The NDI face validity has been ensured through peer-review and patient feedback sessions (Vernon & Mior, 1991). Construct validity is a measure of the scale's responses in comparison to other related assessment tools (Pietrobon et al., 2002). There was a moderate to high degree of correlation ($r = 0.60$) between changes in NDI scores pre- and post-treatment and those of an improvement in the Visual Analog Scale (VAS) (Vernon & Mior, 1991). Moderately high correlations (0.69-0.70) have been found between the NDI and McGill Pain Questionnaire (Vernon & Mior, 1991). The NDI is positively related to a level of pain intensity measured by a VAS (Hains et al., 1998). A moderately high correlation has also exists between the NDI and the McGill Pain Questionnaire (Pietrobon et al., 2002).

Responsiveness is the ability of a scale to detect small, important clinical changes (Guyatt, Deyo, Charlson, Levine, & Mitchell, 1989). The NDI appears to be sensitive to the levels of severity of complaint and to changes in severity in the course of treatment with the average change in NDI over a course of 3 weeks conservative treatment was 33.2% (Vernon & Mior, 1991).

The NDI questionnaire is available at the Canadian Memorial Chiropractic College's website. It has been shown to be both reproducible and reliable (Vernon, 2008). It has strong and well documented convergent and divergent validity with other instruments as well as high reliability and strong internal consistency (Vernon, 2008).